THE ROLE OF RESEARCH IN THE DEVELOPMENT OF FORESTRY IN NORTH AMERICA

BAILEY AND SPOEHR

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THE RÔLE OF RESEARCH IN THE DEVELOPMENT OF FORESTRY IN NORTH AMERICA

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FOREWORD

This modest volume aims to summarize, in as few words as may be, an answer to an unusually significant question. In a paper presented before the National Academy of Sciences in 1924, Colonel W. B. Greeley, then Chief of the United States Forest Service, outlined the gravity of the situation as to present and future national timber resources in proportion to obvious needs, and asked the counsel of the Academy in meeting the situation. Following Colonel Greeley's request, the National Academy appointed a representative group to inquire further into the facts and to report its findings. The publication of the report in this volume presents in some measure the answer of the Academy through its committee to the questions proposed by the Chief of the Forest Service.

Under authority of the National Academy, the Committee accepted from the General Education Board a special grant adequate to proceed with a critical inquiry into the status and needs of research in the sciences basic to forestry. The Academy Committee was fortunate in securing the services of the scientists judged most competent for this detailed survey, namely, Irving W. Bailey of Harvard University, H. A. Spoehr of Carnegie Institution of

Washington, and Henry S. Graves of Yale University. Since Dean Graves has had special interest in forestry education, he undertook the responsibility for inquiry into the existing relations of education to research. Following submission of his preliminary report, the Society of American Foresters considered this matter of so much significance that it sought and secured from the Carnegie Corporation an additional grant for carrying this educational survey forward in a more intensive way than was possible for the Academy committee. The data already secured by the Academy committee have been made available to the Foresters' committee for use in its further study of this important problem.

The authors of the present volume are alone responsible for expression of judgment and opinion, and should be given credit for this contribution to our knowledge and understanding of the subject. The committee of the National Academy expresses its appreciation of the report as justifying the confidence reposed in the investigators selected for this difficult task.

Committee on Forestry Research
National Academy of Sciences

L. R. Jones, *Chairman*
R. A. Harper
I. W. Bailey
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E. D. Merrill

INTRODUCTION

In any discussion of forestry and of programs of research in the general field of forest production,* it is essential to emphasize the fact that a forest is an exceedingly complex biological unit. It comprises not only a more or less diversified aggregation of trees, but numerous species of shrubby and herbaceous plants, fungi, insects, herbivorous animals and a complex soil fauna and flora. In other words, it consists of a very large number of mutually interacting organisms which are affected by, and themselves affect, a complex of environmental factors.

In the case of a normal virgin forest, the biological complex is in relatively stable equilibrium and such changes as are induced by climatic and geological fluctuations are in general very gradual. With man's advent, this natural equilibrium is upset by logging, fire, grazing and other disturbances which initiate numerous and protracted chains of highly involved and extraordinarily variable reactions.

The task of the silviculturist is to control or modify these reactions in order to secure a sustained

* Forestry may be divided into (1) those phases which are concerned with the culture and care of forests, *forest production* or *silviculture,* and (2) those which are concerned with the harvesting and use of forest products, *forest utilization.*

maximum yield of valuable forest products. Frequently he must also bear in mind the effects of different types of forest management upon soil erosion and stream-flow, upon public health and recreation and upon the welfare of the grazing and other subsidiary industries. For economic and other reasons to be outlined on succeeding pages, the silviculturist is forced to deal with relatively natural units of vegetation and cannot, in most cases at least, simplify his problems to the extent that the farmer has succeeded in doing. He can, in general, modify environmental factors and regulate the future growth on timberlands only through intelligently supervised gross treatments of the forest vegetation itself, *i.e.*, by "thinnings," by modifying and properly timing his methods of harvesting, by varying his technique in disposing of brush, by controlling fire and grazing, etc.

Such gross treatments have highly diversified and far-reaching effects upon the biology of the forest, not only upon the soil and the trees but also upon the minor vegetation, insects, fungi, and other elements of the complex. The latter effects cannot safely be ignored since they in turn may later profoundly influence the future growth of the forest. Thus, in developing rational systems of silvicultural management, the forester must take into consideration the whole complex of interactions in the forest and, to do so effectively, he must rely upon the cooperation of various sciences.

The primary object of the following discussion is to determine how and to what extent certain categories of the natural sciences may be of service to silviculture during different stages of its development. Before passing on to a detailed treatment of this subject, it is necessary to comment briefly upon various salient characteristics of these sciences themselves.

All of natural science is observational. During the earlier stages of its development, it concerned itself with describing and comparing the more obvious, complex and grosser aggregates of matter and units of energy. Through the analysis of large volumes of descriptive data, it succeeded in establishing many valid correlations between groups of phenomena. Subsequent search for actual causal relationships has led to the investigation of smaller and less complex aggregates or units, and natural science has resolved itself into a series of subdivisions, each of which deals with particular groups of phenomena and has developed its own specific observational technique. Thus, in the biological field, morphology has passed successively from a consideration of external form (taxonomy and systematic biology) to the study of gross internal structure (anatomy and histology) and finally to the description of the visible structure of living matter (cytology). Similarly chemistry has progressed from the investigation of compounds to that of molecules, atoms and electrons.

Physics and chemistry in passing from the investi-

gation of visible to invisible units were forced to develop highly refined and exact quantitative experimental methods. In other words, they have substituted an intensive analytical technique for an extensive observational one. Only in the study of heredity and in certain aspects of bacteriology has biology succeeded in originating quantitative experimental methods which are comparable to those of physics and chemistry. Most of the biological sciences are still concerned with the investigation of visible phenomena and with the establishment of correlations through cumulative circumstantial evidence; the transition from gross morphology to cytology has involved the use of the microscope, but no radical change in the point of view of the investigator.

It should be emphasized in this connection that plants and animals are so numerous and diversified, and vital phenomena are so complex and so extraordinarily variable, that all of the biological sciences still have important rôles to play in the future. The compilation, codification and analysis of descriptive data and the formulation of valid correlations are not only of great practical significance in the development of the biological arts, but are indispensable in the visualization and definition of those fundamental problems which biology seeks to solve. Nor should it be inferred that this work when well done is of an inferior intellectual quality. The descriptive method requires capabilities and disciplines which are by no means inferior to those used in the exact

sciences. In fact, the successful employment of cumulative circumstantial evidence—*e.g.,* Darwin and the Theory of Evolution—demands qualities which are rarer and often more finely discriminating than those employed in the exact sciences. Thus, although most biological research and experimentation, except when concerned with the simpler physico-chemical reactions in organisms, is essentially descriptive and empirical from the point of view of modern physics and chemistry, it does not follow that it is inferior or less useful.

It is evident accordingly that there are two distinct methods of investigating complex biological phenomena, one the extensive observational method of the descriptive sciences and the other the intensive analytical method of the basic experimental sciences. The former sciences work to establish valid correlations between visible aggregates of variables. The latter sciences aim to resolve these aggregates into their constituent variables and to study these individual variables under accurately controlled experimental conditions. Each line of attack has distinct advantages and limitations, and each requires particular abilities and disciplines and a specific psychological outlook upon the part of the investigator. On the one hand, the descriptive sciences are able to make rapid progress in the study of the visible forms and activities of living matter and in establishing correlations between them, but they are handicapped in determining the underlying fun-

damental whys and wherefores. On the other hand, the accumulation of reliable data through the methods of the basic experimental sciences is a tedious and time-consuming process, and no valid generalizations are possible until a certain essential total of experimental evidence is accumulated.

Both lines of attack appear to be essential in the ultimate solution of the fundamental problems of biology. The descriptive sciences are able to formulate and roughly define these problems, but they are dependent upon the basic experimental sciences for the necessary means of analyzing them accurately. Although physics and chemistry have developed methods for investigating certain of the simpler physico-chemical reactions in plants, they have not succeeded as yet in perfecting adequate techniques for analyzing the more complex vital phenomena. Until such techniques are available, attempts on the part of plant science to solve highly complex and variable biological problems through the use of quantitative experimental methods are of doubtful value. Furthermore, there is a serious question whether the methods of the descriptive and of the exact sciences can be combined successfully in the hands of a single investigator. Occasionally an exceptional individual may be able to master modern physics and chemistry and one or more of the descriptive sciences, but most investigators are unable to do so and tend to become more or less superficial in all fields. Thus, much of the so-called "modern

fundamental" biological research is unfortunately an aimless puttering with quantitative methods and is unproductive from the point of view both of the descriptive sciences and of the basic experimental ones. The phenomena to be investigated are so complex and variable that, in many cases at least, they can be analyzed accurately only through the active cooperation of a group of experts in physics, chemistry and biology.

The utilization of scientific data in the arts is dependent (1) upon the stage of development of the art, (2) upon the stage of development of the sciences and (3) upon economic factors. The descriptive method coupled with simple empirical experimentation is of maximum service during the pioneer stages of a biological art, since it affords the most economical and rapid means of establishing such correlations between dominant factors or between groups of phenomena as are of practical significance. Eventually this line of attack tends to exhaust its most promising possibilities and during the later stages of the development of the art there is an increasing necessity for truly fundamental experimental research.

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THE RÔLE OF RESEARCH IN THE DEVELOPMENT OF FORESTRY IN NORTH AMERICA

CHAPTER I

Agriculture as Contrasted with Silviculture

The natural production of plant food, suitable for man's consumption, on wild or uncultivated lands is extremely low. Therefore, agriculture is essential for the development of even relatively primitive civilizations, and it is significant in this connection that all of the more important plant foods were discovered and brought into cultivation by prehistoric man.

Prolonged investigation of the earth's terrestrial vegetation indicates that first class food-producing plants are limited in number. Indeed, at present the bulk of the world's food is produced by a relatively few species, and increased production is secured largely by bringing successive areas of wild land under cultivation of selected or "improved" races of these species, rather than by the domestication of endemic wild species. Of course, the growth of selected races or of hybrids in pure cultures beyond the limits of the native habitats of their progenitors is, from the biological point of view, a highly un-

natural process, and necessitates considerable expenditures for controlling environmental factors, *e.g.*, by drainage, irrigation, tillage, use of fertilizers and protective sprays, rotation of crops, etc.

Each agriculturally used species produces one specific primary product. The market requirements for these primary products are relatively highly standardized and stable, and there is little evidence to indicate that they will not remain so. The possible substitution of synthetic products for natural plant foods must at best be relegated to the distant future.

In the case of forest products, as contrasted with plant foods, the accumulation * of utilizable material on wild lands is very high. Furthermore, logged-over areas commonly are capable of yielding additional crops, particularly in more moist environments and in regions where protection is afforded against fire and grazing. In fact, successive crops of considerable magnitude and value may be secured without special cultural treatment. Thus, silviculture of an intensive type becomes essential only after sources of wild forest products become exhausted and when costs of imported material become excessive.

The world's list of trees which now produce, or may in the future yield, valuable raw material is

* Wood is chemically a relatively stable substance and accumulates in a tree from year to year. On the contrary, seeds, nuts, fruits, etc., are perishable and must be harvested at the end of each growing season.

very extensive. A sustained industrial utilization of forest products has been, and is still being, secured largely through the harvesting of the accumulated material of one after another of these wild species, rather than by extending the cultivation of a few highly domesticated species as in agriculture. Many species of trees are capable of yielding a variety of different types of material, *e.g.*, fire wood, posts, ties, lumber, pulp, distillates, chemical extracts, etc. Furthermore, the raw products of different species are to a considerable degree potentially interchangeable. In addition, there are substitutes for wood in most of its varied uses. Thus, the market requirements for specific forest products are much less stable and assured than is the case in agriculture.

Such facts as these raise the question, will silviculture, after the world's virgin forests have been logged over, tend to develop along lines closely parallel to those of agriculture? This question is of vital significance in any general discussion of forestry and of future programs of research in the field of silviculture.

There are five points which should be emphasized in this connection:

(1) In the future, forests will be grown mainly on lands which cannot be used advantageously for agriculture; *i.e.*, on less fertile soils and steeper slopes where cultivation, in the agricultural sense, is relatively difficult.

(2) Even on potentially tillable lands the character, size and longevity of forest plants renders difficult the application of agricultural methods.

(3) The value of forest crops will rarely justify any considerable expenditure for directly controlling environmental factors by tillage, irrigation, use of fertilizers, sprays, etc. Thus, the forester will in general be restricted to the use of relatively inexpensive and more or less indirect methods. He will be forced to control forest growth and to modify environmental factors largely through his treatment of the forest vegetation itself.

(4) Forests are widely distributed natural units of vegetation; and, as previously indicated, may be made self-perpetuating and highly productive through relatively inexpensive treatments.

(5) Industrial and other requirements for wood are so varied and relatively plastic that it will be possible to market the products of a wide range of arborescent species of forest plants. This is due, of course, to the fact that the wood of most species has a wide range of possible commercial uses.

It is evident, accordingly, that silviculture will be concerned, at least for an extended period, with the modification of relatively natural units of vegetation and with the restoration of more or less natural arborescent growth on devastated areas, rather than as in agriculture with extending the culture of a limited number of highly domesticated species under comparatively artificial conditions. That such is in-

deed the case is indicated by a strong reaction among silviculturists, particularly those of Northern and Western Europe, against the more artificial systems for regenerating and managing forests. In fact, a number of the ablest European foresters are of the opinion that silviculture should aim to reproduce as natural units of forest vegetation as possible, since such systems of forest management are held to be the most productive in the long run, to obviate serious deterioration of the soil and to reduce losses due to insects and plant diseases. Of course, this does not mean that certain species of trees may not be grown ultimately in more or less pure cultures as such units of vegetation occur naturally, especially in the temperate regions. Nor does it necessarily eliminate the possibility of successfully establishing selected races or desirable exotics, but it renders difficult and uncertain the task of so doing. It does indicate that stereotyped systems of silviculture, such as have been developed in certain portions of Central Europe, cannot be practised extensively in other phytogeographical regions. Each system, if actually efficient, is adapted to meet the requirements of a specific, local complex of factors, and, therefore, must be modified more or less profoundly when applied in a different region.

Most agricultural crops are grown on short rotations and by cultural methods which have become relatively highly standardized. Even the longer lived nut- and fruit-bearing species yield annual

harvests after a brief preliminary period. In other words, the character of the investments and returns in agriculture is such that the art is practised extensively by individuals on relatively small holdings of land. On the contrary, long rotations in silviculture, coupled with uncertainties concerning future market requirements and other economic variables, tend to inhibit the development and practise of the art by individuals and by any except the most far-sighted communities. Thus, silviculture is practised during relatively late stages in the development of civilization, and, even in regions where sources of wild forest products have been exhausted, by a few of the most progressive countries only. Indeed, Zon and Sparhawk estimate that at present "only 10-15 per cent of the world's timberland is being handled as a renewable, continuously productive resource." *

* Forest Resources of the World. McGraw-Hill. Vol. 1, page 35, 1923.

RESEARCH AND ITS APPLICATIONS IN SILVICULTURE AS CONTRASTED WITH AGRICULTURE AND MEDICINE.

CHAPTER II

Research and Its Applications in Silviculture as Contrasted with Agriculture and Medicine.

MEDICINE is of necessity closely dependent for efficient development upon scientific research, and has reached a stage where future progress depends largely upon the results of investigations in the more basic, experimental aspects of the physical, chemical and biological sciences. It is inherently an art in which there is a wide range of possibilities for the direct application of specific, fundamental, scientific discoveries.

The higher animals, particularly man, in contrast to terrestrial plants are not attached to, or directly dependent for part of their nutritional requirements upon, the soil. Their motility and habit of ingesting food facilitate their observation and treatment under relatively rigidly controlled environmental conditions. Furthermore, their highly specialized and clearly differentiated respiratory, digestive, circulatory, etc., systems simplify the task of studying and of directly modifying internal physiological processes. Of even greater significance, however, is the fact that life and health are matters of vital importance to most members of the human race. *There-*

fore comparatively large expenditures are available for the treatment of single individuals. The strong altruistic appeal of medicine is, of course, an additional factor in providing liberal funds for research and its applications in alleviating the suffering of mankind in general.

Agriculture is in the midst of a prolonged period of expansion, the extension of known cultural methods to successive areas of wild land, which has been rendered possible largely through the development of farm machinery and through improvements in the transportation, storage and utilization of agricultural products.

As previously stated, all of the more important food-producing species of plants were discovered and brought into cultivation by prehistoric man. This was accomplished by a long process of "trial and error." Subsequent improvement of these plants through selection and breeding, and the development of more efficient cultural techniques have been attained largely through empirical investigation. The rôle of the basic sciences has in general been that of *ex post facto* interpretation, clarification and modification, rather than the actual origination of new cultural methods. It should be noted in this connection that, although genetics is providing a scientific basis for the arts of animal and plant breeding, the bulk of the numerous, improved races and varieties, *now in use,* was developed by essentially empirical methods.

In agriculture, as contrasted with medicine, expenditures for cultural treatments are determined by strictly economic, rather than humanitarian, factors. The farmer in most cases must deal with individuals *en masse, i.e.,* with aggregates of plants which are attached to, and are dependent for their existence upon, specific edaphic complexes. He can affect internal physiological processes only indirectly through relatively limited and gross methods of modifying external environmental factors, *e.g.,* by tillage, irrigation, fertilizers, rotation of crops, etc. Thus, the range of possible direct applications for specific researches in the fundamental sciences is considerably restricted.* Only in the field of genetics has agriculture a conspicuous advantage over medicine.

There are obviously three salient means of increasing the future yields of agricultural products on cultivated lands: (1) by the selection and breeding of improved stocks or races of crops, (2) by eliminating or reducing losses due to pests and diseases and (3) by more efficiently controlling external environmental variables and intelligently regulating their effects upon internal physiological processes. As previously noted, genetics is rapidly providing a more scientific means for approaching

* This statement refers to those phases of agriculture which are concerned with the *growing* of crops. The situation is entirely different as regards research in the *utilization* of agricultural products. Animal husbandry is in many respects more clearly comparable to medicine.

the first of these objectives. Bacteriology, entomology and phytopathology, through an intensive study of the life histories of bacteria, fungi and insects, are contributing materially toward a more effective control of pests and diseases, but, in so doing, are in general restricted to the external application of fungicides and insecticides, the reduction of external sources of infection and the development, in co-operation with genetics, of disease resistant types of crops. Although soil science and plant physiology are making some important progress in their attack upon the third objective, their advance is comparatively slow and falls far short of fulfilling earlier expectations. This is due to the fact that the plant and the soil in which it grows form two extraordinarily complex, interacting systems of physical, chemical and biological variables. It is extremely difficult to isolate specific individual factors and to devise adequate methods for studying them under accurately controlled experimental conditions; or, having done so, to determine their exact effects upon other variables in the complex. Only a beginning has been made in the development of methods for the study of the water relations of plants, probably the most important single factor. The same is essentially true for the temperature relations. Such fundamentally significant physico-chemical phenomena in the plant as photosynthesis, the synthesis of carbohydrates, fats and proteins, respiration, osmosis, etc., are still imperfectly understood. Relatively

little is known concerning the actual functions of various tissues, the physico-chemical reactions involved in their differentiation, and the translocation of salts and of elaborated products within them. Furthermore, there is a host of complex organic substances, *i.e.*, latex, oleoresins, glucosides, tannins. gums, alkaloids, etc., whose rôle in the vital activities of plants is at present entirely obscure, and a large number of physiologically important substances which have never been subjected to thorough chemical study.

Not only are soil science and plant physiology seriously handicapped in their possible service to agriculture by the present inadequate state of knowledge concerning the complex of physico-chemical reactions in the plant and concerning the complex of interacting physical, chemical and biological factors in the soil, but so also are plant pathology, entomology and genetics. The phenomena in the plant and in the soil are so complex and variable that efficient progress toward elucidating them can be made only through a prolonged and sustained attack by physics, chemistry and biology working in close cooperation. To be successful such an attack should not be shackled by demands for practical applications. Unfortunately, agriculture does not afford as urgent a spontaneous stimulus for the development of truly fundamental research in plant physiology as does medicine in the general field of animal physiology. The range of possible direct applications for

specific scientific discoveries is considerably restricted by economic factors. Therefore, in the absence of a strong humanitarian appeal, it is difficult to justify the expenditure of public funds for protracted basic researches, which may not yield practical results until a certain *essential total* of biophysical, biochemical and biological information is accumulated.*

SILVICULTURE is of necessity a more plastic and adaptable art than is agriculture, due to the fact that it is concerned with essentially natural and varied, rather than with highly artificial and stereotyped, units of vegetation, and therefore must modify or revise its methods to meet the requirements of varying complexes of natural and economic factors. There are at present no sound, well established, fundamentally scientific generalizations for determining in advance the best cultural treatment of a new unit of forest vegetation. Even in those regions, *e.g.*, Europe and Japan, where silviculture is most intensively practised, it has developed almost entirely through an efficiently systematized empiricism. *Thus, the extension of silvicultural management over the earth's vast area of wild forest land must be preceded by a comprehensive descriptive survey and analysis of widely fluctuating natural and economic variables, and by an intelligently for-*

*It should be emphasized here that whereas medicine is concerned with one organism (man) in health and in disease, agriculture is forced to deal with a variety of crop plants, each of which must be studied intensively.

mulated program of empirical experimentation—a task, the magnitude and importance of which are not generally recognized by biologists. In other words, from the point of view of the world as a whole, silviculture, in contrast to agriculture, is in the incipient, pioneer stages of its development.

In all probability the basic sciences can contribute most effectively to the extension of silviculture by helping to systematize and accelerate the process of accumulating essential data, and by aiding in their analysis and interpretation, rather than by attempting prematurely to originate fundamentally scientific, silvicultural techniques. The forester must first of all be equipped with reliable information concerning the identity of the numerous organisms with which he is called upon to deal, their complete life histories, their distribution in relation to salient environmental factors and their natural association in varying mixtures. Such information is now available for limited areas only, and the descriptive sciences, *i.e.*, systematic botany, systematic entomology, mycology, morphology, ecology, meteorology, physiography, etc., should contribute materially in its accumulation. However, in order to do so efficiently, they must in many cases develop a broader and less stereotyped outlook and devote more attention than heretofore to an accurate visualization of the forester's problems.

Although the rôle of the descriptive sciences in a reconnaissance of the world's forests is obvious and

relatively simple, that of the basic experimental sciences, *e.g.*, physics, chemistry, physiology,* soil science,* genetics, etc., is more or less obscure and difficult. The latter sciences should, of course, endeavor to devise reliable quantitative methods for measuring both external environmental variables and internal physiological factors, and for accurately investigating their interactions. But the phenomena to be analyzed are so complex and so extraordinarily variable, and the time factor in experimentation with arborescent plants is so large, that real progress toward attaining these objectives must inevitably be very slow. It should be emphasized in addition that, owing to their size and longevity, trees must be studied *in situ;* they cannot readily be grown to maturity in the laboratory as are many agricultural plants. *In fact, a special physiological technique must be elaborated for their investigation.* Therefore, there is a grave question as to how far the forester may profitably count on the basic experimental sciences for assistance during the pioneer stages of the development of silvicultural management on wild forest lands.

Even in regions where silviculture is most intensively practised, the forester can modify internal physiological reactions and external environmental factors only indirectly in most cases through relatively inexpensive gross treatments of the forest vegetation itself, *e.g.*, "thinnings," improvement cut-

* Fundamental physico-chemical aspects.

ting, modifying and properly timing methods of harvesting, varying technique in planting and in disposing of brush, etc. In other words, the range of possible direct applications for specific scientific researches is greatly restricted in silviculture as contrasted with medicine or even with agriculture.* Thus, forest entomology and forest pathology cannot in most cases resort to a wholesale use of insecticides and fungicides, and plant physiology and soil science usually cannot justify periodically recurring heavy expenditures for fertilizers, irrigation, tillage, etc. Furthermore, although genetics occupies at present by far the most strategic position of any of the basic experimental sciences, it is not evident as yet how materially it can contribute to an increased production of forest products. It certainly cannot do so as directly and easily as is possible in agriculture.

In the first place, the length of the life cycle in trees is a serious obstacle. The forest geneticist must concern himself mainly with the selection of promising races or varieties and with the production of vigorous first generation hybrids rather than with an elaborate program of breeding which involves an intensive study of many successive generations of plants. As in horticulture, he must depend largely upon vegetative propagation for eliminating variability. In the second place, the forester must pro-

* Those phases of animal husbandry which are concerned with the grazing of animals on uncultivated lands are in certain respects more nearly comparable to silviculture.

ceed with considerable caution in attempting, as in agriculture, to grow selected races or hybrids in pure cultures, *since the more artificial a unit of forest vegetation becomes the greater the necessity for a compensating control over environmental factors.* It should not be inferred from this, however, that exotic species or selected races may not be substituted for existing elements of a specific "forest type" provided this can be accomplished economically and without unduly disturbing the natural equilibrium of edaphic and biotic factors. In fact, most of the so-called wild species of trees when carefully analyzed will resolve themselves into aggregates of more or less numerous morphologically and physiologically distinct races. The isolation, and exchange and trial under varying climatic, edaphic and biotic influences, of the most promising of these races will ultimately become an international problem of considerable magnitude, and one in which systematic botanists, geneticists and silviculturists may profitably cooperate.

It is evident that, not only is the forester forced to deal with more complex and variable phenomena than is the farmer, but his means of controlling them are less tangible and direct. Therefore, the basic experimental sciences can, in the long run, be of maximum service to silviculture by a concerted attack which aims to advance the general status of knowledge concerning forest phenomena, rather than by isolated and uncoordinated investigations of

specific practical aspects of the forester's problems.

The situation in the field of forest production is in marked contrast to that in the field of forest utilization, where specific scientific researches, particularly those dealing with the physico-chemical properties of forest products, have a wide range of possible immediate and direct practical applications.

Plant physiology and soil science, and indirectly plant pathology, genetics, plant anatomy and other divisions of plant science, as previously stated in our discussion of agriculture, are seriously handicapped at present by inadequate information concerning physico-chemical reactions in the plant and in the soil, and by a lack of accurate quantitative methods for studying them under controlled experimental conditions. The situation is merely intensified in silviculture, since relatively less is known regarding trees and forest soils and less progress has been made in devising methods for investigating them. *Thus, any coordinated program for basic scientific research should center about a nucleus of biophysical and biochemical investigations.*

It should be emphasized again in this connection that silviculture must depend mainly upon critical observation in the field and upon empirical experimentation during the pioneer stages of its development. This fact should be clearly recognized and frankly admitted in order to obviate unwarranted expectations both upon the part of foresters and of

scientific investigators concerning the rôle of truly fundamental research, and to prevent misguided efforts. From a strictly utilitarian point of view, a comprehensive program of research in the basic experimental sciences can be justified only through its ultimate, rather than its more immediate, practical applications. This renders difficult the expenditure of industrial or public funds for such researches, since they must be supported over a more or less prolonged period before tangible results may be expected. However, the time factor in forest experimentation is so long and the phenomena to be investigated are so complex and so extraordinarily variable that a clearly visualized and adequately financed program of basic scientific research should be initiated as soon as possible if it is to contribute materially during the later stages of the development of the art of efficiently managing the earth's timberlands.

PRESENT STATUS OF THE FORESTRY MOVEMENT IN THE UNITED STATES.

CHAPTER III

Present Status of the Forestry Movement in the United States.

Nearly one half of the total land area of the United States originally was covered with forests. There were approximately 822 million acres of potentially valuable timber forests; a national resource which, as regards quantity, quality and variety of forest products, surpassed that of any other similar area of the earth's surface. It is estimated that clearing for settlement, fire, grazing and destructive logging have reduced this vast heritage to 139 million acres of remaining virgin forests, 250 million acres of spontaneously regenerating second growth forests of more or less commercial value and 81 million acres of devastated timberlands which must be restocked by planting or other artificial measures. In addition, there are said to be 80 million acres of naturally scrubby woodlands which are capable of producing limited quantities of firewood, fencing and other minor products only.

Prior to 1850 little thought was given to the significance of forests in the future development and welfare of the Nation. To the pioneer, the forest was an actual enemy, an obstacle to be destroyed in

clearing land for settlement. Supplies of forest products generally were regarded as being inexhaustible, and it was not until the scarcity of accessible timber became accentuated in the more densely settled eastern portions of the country that discussion arose concerning possible means of securing a future supply. Between 1868 and 1875 attempts were made by a number of the individual States to encourage the growing of timber through bounties, exemption from taxation and penalties for setting forest fires. This movement did not prove to be effective and was followed by an increasing agitation for conservation of the Nation's remaining supply of virgin timber.

The Organic Act of 1891 authorized the President to set apart portions of the public domain as forest reserves, and large areas were withheld from alienation, particularly in 1897 and during the administration of President Roosevelt. The Administrative Act of 1897 provided the necessary machinery for handling such reserves, but it was not until 1905 that they were transferred from the jurisdiction of the Department of the Interior to that of the Department of Agriculture and placed under the supervision of technically trained foresters.

Although the forestry movement was late in starting, it has made considerable headway during the last 30 years. The creation, protection and administration of 158,759,000 acres * of National Forests in the United States and Alaska, an area larger than

* Not all of this acreage is productive timberland.

the whole of Germany, is in itself a truly great accomplishment. It has involved constant effort in extensive campaigns for educating the general public and has necessitated the winning of a succession of vitally significant political battles against powerfully entrenched interests; the magnitude and difficulty of this task are not fully appreciated. In spite of such distractions as these, the Federal Forest Service under Pinchot, Graves and Greeley has developed a large personnel of increasing administrative and technical efficiency, and one which, as regards public spirited service, integrity and *esprit de corps,* is not surpassed by any governmental agency.

Forty-two States have organized forest services, but most of them, with the exception of New York and Pennsylvania, have not made much headway as yet in the acquisition of State forests. In fact, there are at present only 5,500,000 acres of state-owned forest lands under administration for public purposes. The State forest services have in general devoted their efforts rather towards encouraging a better handling of privately owned timberland; through control of forest fires, revision of existing systems of taxation, dissemination of technical information and the distribution of stock for forestation.

In 1898, when the first forestry schools, those at Cornell and Biltmore, were started there were very few foresters in the country, a mere handful of men who had studied in Europe. The organization of the

Federal Forest Service and of various State services, calling as it did for a relatively large number of technically trained men, stimulated the rapid development of additional schools. There are now 25 educational institutions of collegiate and post-collegiate rank which confer degrees in forestry; nearly as many as in the whole of Europe. A majority of these schools are housed in new buildings with well equipped class-rooms and laboratories, and many of them have acquired, or are in the process of acquiring, forests for demonstration and experimental purposes. Thus, as regards numbers of students, the United States is fully as well equipped as Europe for training such men as will be needed in the immediate future. It should be noted in this connection, however, that American educational standards and requirements are quite different from those of Europe. At present, more students are graduated than can be absorbed by the Federal and State forest services, and several of the American schools are devoting more and more attention to the training of men for purely industrial and commercial lines of work where there is little opportunity for applying any considerable amount of silvicultural and general biological information.

In discussing the present status of the forestry movement in the United States and in evaluating the progress that has been made during the last 30 years, it should be emphasized that the forestry profession has of necessity been forced to concern

itself mainly with the difficult task of paving the way for the future development of silviculture, rather than with the actual practise of the art in an intensive form. Most of the criticism of the profession, for not having applied European systems of forest management or for failing to develop "truly scientific" methods, is based upon misconceptions. It is not clearly recognized that an intensive silviculture can evolve only under highly favorable political, economic and industrial conditions, and that European silviculture developed gradually through a prolonged process of empiricism and of adaptation of methods to meet the requirements of specific local complexes of natural and economic factors.

The most vitally important task of American forestry has been, and still is, the salvaging from fire, grazing and destructive logging of as large an area of productive timberland as possible. The improvement of spontaneously regenerating forests is a difficult and time-consuming undertaking, but is a relatively simple one as contrasted with that of reforesting devastated areas. It is necessary merely to consider the strenuous efforts that were made in France, and are now being made in England, in restocking a few million acres of land, to appreciate the magnitude of the task of reclaiming the existing 81 million acres of seriously deteriorated timberlands in the United States. To allow large additional areas of forest land to pass into this category would be disastrous.

The creation and efficient administration of the National Forests, although a notable achievement, has assured an adequate protection for only one fifth of the Nation's timberlands. Four fifths remain in the hands of private owners; 150 million acres in "farmer's woodlots" and 221 million acres in larger holdings. The protection of these privately owned timberlands is still a critical and pressing problem. There are three means of solving it, (1) by increasing the acreage of Federal, State and Municipal holdings, (2) by regulating the handling of privately owned timberlands as is done in certain European countries and (3) by stimulating private owners to manage their timberlands upon a sustained yield basis. Some progress has been made along each of these lines, but thus far it has been discouragingly slow.

The history of the development of European forestry has led to the belief that at least one third of a nation's timberland should be held under public ownership. In the United States, this would mean the addition through purchase or other measures of approximately 60 million acres of privately owned timberlands to the present holdings of Federal, State and Municipal forests. Since the passage of the Week's Law in 1911, the Federal Government has purchased some two million acres, principally on the headwaters of navigable streams. It is evident that the process of increasing the açreage of publicly owned forests must be considerably accelerated

if it is to figure materially in the protection of cut-over lands. Particularly should the States assume a more important rôle than they have heretofore.

Owing to serious political and economic obstacles, it has not been possible to make any significant headway in directly regulating grazing and logging operations on privately owned lands. Considerable progress is being made, however, in controlling fire which is, of course, the most destructive single factor. The Federal Government is cooperating effectively with many of the States, but, in spite of strenuous efforts upon the part of Federal and State forest services, less than half of the 371 million acres of privately owned timberland is protected from fire. In 1924, there were 92,000 fires which burned over more than 22 million acres of forest land.

The third possibility, that of stimulating private owners to operate their timberlands upon a sustained yield basis, and therefore voluntarily to protect their own forests, also is a difficult and time-consuming task. It involves the revision of existing systems of taxation, the stabilization of forest land ownership and the readjustment of a complex of unfavorable economic and industrial factors. In addition, it is essential to overcome the natural handicap of deferred financial returns on long rotations.

Although a number of lumber companies are expressing a more or less sincere interest in permanent land ownership and are experimenting with forestation, it is not possible at present to forecast how far

this movement will extend. Much will depend upon initial successes or failures. Relatively large holdings of mature or nearly mature timber are required to tide such companies over an initial transitional period. Therefore, the most favorable regions for a rapid development of this movement should be the Pacific Coast and portions of the South where there are extensive stands of mature timber in private ownership and where the growth of coniferous species is unusually rapid. Unfortunately the general economic and financial status of the lumber industry, particularly in the Pacific North West, tends to encourage an extremely wasteful and destructive, rather than a conservative, type of forest utilization.

The second growth forests on the cut-over timberlands of the North Eastern and Lake States are commonly of inferior quality. The more desirable species have to a considerable extent been replaced by less valuable ones. The improvement of these timberlands is largely dependent upon the development of profitable methods for disposing of a large volume of low grade material. Much effort will have to be expended to prevent these lands from being culled for their more valuable material without regard to their future productiveness.

In the case of the 150 million acres of farmer's woodlots, there are a number of factors which should favor the application of simple silvicultural treatments. This class of private ownership is a relatively stable one. The farmer is accustomed to dealing with

plants and therefore should be able to grasp the significance of specific cultural techniques and to apply them effectively. Furthermore, he is able to utilize a considerable volume of material which may be removed in making thinnings and improvement cuttings. It is significant in this connection, however, that progress in educating the farmer and in inducing him to improve his woodlots will be gradual. The rewards for his labor are too long deferred and under present economic conditions are too uncertain to afford a strong stimulus for the application even of relatively simple silvicultural treatments.

Such facts as these indicate very clearly that forestry in the United States is still in its pioneer stages. *It must solve a complex of extremely difficult and involved sociological, political, economic and industrial problems before it can hope to make rapid headway with the application of intensive silvicultural methods.* This is true even as regards the administration of the National Forests. In other words, the development of American silviculture is dependent upon the formulation of a sound national forest policy which is clearly visualized and is wholeheartedly supported by the general public, by timberland owners and by wood-using industries.

As previously stated, European silviculture developed gradually through essentially empirical investigations. There are no sound, well established, fundamentally scientific generalizations for deter-

mining in advance the best cultural treatment for a new unit of forest vegetation. Therefore, although American forestry may profit materially from European silvicultural experience, it must develop cultural methods to meet the requirements of its own specific complexes of natural and economic factors. Thus, in the immediate future, it will be concerned mainly with the adjustment and stabilization of economic factors, and with the development of relatively simple measures for securing a regeneration of existing forests and for improving the growth on cut-over lands. The transition towards a general application of truly intensive silvicultural methods will of necessity be gradual.

In Europe, there are a few score of indigenous arborescent species only, a very limited number of which are of real economic significance. On the contrary, in the United States, there are hundreds of tree species, and a large number of them are of potential value from a forest utilization point of view. Not only is the American forest flora rich in species, but these species occur in a wide range of mixtures or associations and in highly diversified environments. To determine the best silvicultural treatments for so many different units of natural forest vegetation, particularly when they have been modified in various ways through fire, grazing and logging, is a laborious undertaking, and one which will require the compilation and analysis of large volumes of reliable descriptive data and extensive

programs of carefully planned and efficiently supervised empirical experimentation.

While it is true that American forestry can profit from the experience of European countries and much can be learned from the achievements and mistakes of the older undertakings, America, nevertheless, occupies an unusual and strategic position. It is generally recognized that a matter of vital importance to various aspects of silviculture is the study of the factors and conditions, climatic and edaphic, which play a rôle in the development of the natural forest. For this purpose virgin conditions are of critical significance. The opportunities for field investigation and experimentation over an enormous range of natural conditions and with a great variety of species in the extensive forest tracts of North America, offer facilities far beyond those of Europe, with its many political boundaries, lack of virgin forests and paucity of arborescent species. In Europe the original vegetation and other conditions have been so extensively transformed by man that it is exceedingly difficult to reconstruct natural conditions. In America, particularly the western portion, opportunities for studying undisturbed original conditions and influences still exist. There are also effective means for preserving these conditions. America thus occupies a most important position and possesses opportunities for advancing knowledge of forestry which will be of direct service to the entire world.

EXISTING AGENCIES FOR DESCRIPTIVE AND EMPIRICAL EXPERIMENTAL INVESTIGATIONS IN FORESTRY.

CHAPTER IV

Existing Agencies for Descriptive and Empirical Experimental Investigations in Forestry.

In the United States the institutions which are devoting attention to descriptive and empirical research are numerous and diversified in character. These institutions include Federal and State agencies, forestry schools and other educational institutions as well as industrial and private organizations. Although many of the investigations undertaken by these agencies are of an intensive and often elaborate character, they are nevertheless of the descriptive and empirical type. The avenues of attack and the problems under investigation naturally are also varied and range from the comprehensive program of the Federal Forest Service to special problems of the wood-using industries. A complete description of the activities of these agencies would lead beyond the domain of this discussion; they are considered in detail in a recent publication,* prepared by E. H. Clapp for the Society of American Foresters. Only their salient aspects need be touched upon here.

* A National Program of Forest Research. Published by the American Tree Association. 1926.

In view of the fact that the United States has been concerned mainly with the harvesting, rather than with the culture, of timber, it is not surprising that it should have made relatively greater headway with research in forest utilization than in forest production. Not only has the United States made notable advances in the development of improved tools and machinery for use in logging operations, sawmills and wood-using industries, but also in the investigation of the properties of forest products and of industrial processes. The Federal Forest Products Laboratory is generally recognized as the leading institution of its kind in the world, and is being used as a model by several countries which are organizing laboratories for research in the forest utilization field. Its investigations constitute a coordinated attack on a large group of eminently practical problems.

As previously stated, the development of American silviculture is dependent upon the solution of a wide range of economic and industrial problems. Therefore, extensive investigations in forest utilization are essential, not only in formulating a rational policy for handling America's timberlands, but in developing efficient programs of research in forest production. Take, for example, the critical problem of disposing of large volumes of low grade and inferior wood in the North Eastern and Lake States forests. There are a number of recent industrial developments which suggest that a considerable por-

tion of such material may be utilized profitably for pulp and other chemically derived products. If such proves to be the case, the silvicultural management of these timberlands, and research in forest production, will be influenced profoundly thereby.

It should be emphasized in this connection, however, that the future utilization of forest products is dependent upon the growing of timber, and that, owing to the long time factor in silvicultural experimentation, extensive research in forest production cannot safely be deferred until the remaining virgin forests have been logged over. In other words, research in forest utilization and in forest production should be concatenated and progress in the two fields should be synchronized.

Although research in forest production occupied for many years a relatively subordinate and impecunious position in the United States, rapid progress has been made since 1920 in remedying the situation through the organization of a series of eleven Federal Forest Experiment Stations. The following quotations from "A National Program of Forest Research" may be considered to give an authoritative description of the aims and activities of these experiment stations, since they were written by the Assistant Forester in charge of Federal forest research.

"The underlying conception has been that each station would work on problems of a region of similar forest conditions, as for example, that of the

Lake States where a group of forest types characterized mostly by the predominance of white, Norway, and jack pine and of the northern hardwoods—birch, beech, maple and aspen—extends over much of Michigan, Wisconsin and Minnesota. The organization of each station consists of a central headquarters, preferably with university contact, from which the permanent technical staff works out as necessary to a series of field branches or experimental and demonstration forests representative of important subregions."

"Gradually, however, the extreme diversity as well as the ultimate unity of the timber growing problem has been realized and the need for fully rounded-out forest research centers has gained recognition. Cooperative plans are well advanced, therefore, under which the Bureaus of Plant Industry and Entomology, respectively, are assigning forest pathologists and entomologists to the stations and may in the future be carried still further by the addition of zoologists and other specialists. When manned with a well rounded-out staff of investigators, many-sided attacks on both regional and national problems are possible and the stations have the opportunity to become forestry centers of commanding influence. They have all the inspirational and other advantages which attack on a single problem of national importance will bring. The stimulus to the research staff may be extended to other research agencies in the region, and may be made a strong influence in the general development of both public and private forestry. The regional forest experiment

stations are also proving themselves directly or indirectly to be valuable correlating agencies for all forest research in their respective regions."

"The great handicap of the regional forest experiment stations is the rapidly growing demand for answers to specific problems growing out of the development of both public and private forestry. Encouraging though this pressure may be as an indication of progress in the utilization of our forest land, it sometimes necessitates more emphasis on immediate questions than the most efficient conduct of the work alone would require. Other handicaps of inadequate funds and of difficulty in obtaining suitably trained men are common to all organizations doing forest research."

The general policy for the development of research in forest production, outlined in the preceding quotations, appears to be a sound and far-sighted one and deserves the support that it is to secure through the McSweeney-McNary bill. This bill provides, during a 10 year period, for greatly increased annual expenditures in the following lines of research.

Forest Production

Regional Forest Experiment Stations ...	$1,000,000
Forest Grazing Investigations	275,000
Forest Protection	
Bureau of Plant Industry	250,000
Bureau of Entomology	350,000
Weather Bureau	50,000
Forest Zoology, Biological Survey	150,000

Forest Utilization	
Forest Products	1,050,000
Forest Economics	
General Forest Economics	250,000
Special Survey of Timber Resources and Requirements	250,000
Total maximum annual expenditure .	$3,625,000

As interpreted by the Forest Service, the implication of the McSweeney-McNary bill as to the organization of forest research in the Department of Agriculture is towards

(1) a forest products research laboratory at Madison, Wisconsin, at which will be concentrated various investigations in the general field of forest utilization, and

(2) regional experiment stations at which will be centered the bulk of research in forest production. The bill authorizes the establishment of five additional stations; one for the intermountain region of Utah and adjoining states, one for Alaska, one for Hawaii, one for the tropical possessions of the United States in the West Indies and one additional station for the southern states.

The general trend in organization is towards a gradual concentration at the regional forest experiment stations of all local or regional investigations, including research upon special problems in the fields of forest utilization and forest economics as well as research in forest production. To meet the

needs for a central silvicultural unit, the Forest Service has established, and plans to continue, a silvicultural section at the Forest Products Laboratory. This unit incidentally will cooperate in many lines of research at the Forest Products Laboratory which are rapidly trending toward the silvicultural field. In addition, the Forest Service is urging other Federal bureaus, *e.g.*, Bureau of Plant Industry, Bureau of Entomology, Biological Survey, etc., to assign investigators to the regional forest experiment stations or to the Forest Products Laboratory, depending upon the character of the research involved. Such a scheme of organization, backed by the provisions of the McSweeney-McNary bill, ultimately should lead to more effective cooperation between the various Federal agencies which are concerned in the investigation of forestry problems. Furthermore, the McSweeney-McNary bill authorizes cooperation with individuals and with public and private agencies, organizations and institutions.

Besides the Forest Service, which is supported by the Federal Government, forty-two of the States in the Union now support forestry departments. Most of these departments are concerned primarily with general educational efforts, fire protection, revision of taxation, the distribution of stock for artificial forestation and in certain cases with the acquisition and management of State forests. Purely administrative duties, combined with a more or less strenuous financial and political struggle for ex-

istence, have militated against extensive research activities in most States. Where research is attempted, as, for example, in Pennsylvania, Maryland, New Jersey, New York, New Hampshire, Michigan and California, it is of necessity on immediate and practical problems, and much of it is concerned with problems in the general fields of forest economics and forest utilization rather than in that of forest production. The greater portion of the work in the latter field has dealt with local aspects of artificial and natural forestation, growth and yields, life histories of forest trees, forest diseases, and similar subjects. In agricultural sections the management of farm woodlots has taken the attention of the State forest departments and has thus naturally merged with the work of the agricultural experiment stations and agricultural colleges.

The first forest schools in the United States were modeled very closely upon the pattern of European institutions. Emphasis was placed upon a general biological training and upon the study of European methods of handling forests. With a clearer visualization of the serious obstacles to be overcome in the development of silviculture in North America, most of the schools gradually revised their curricula, devoting more and more attention to the administrative, economic and industrial aspects of forestry. Thus, a very considerable portion of the average student's time has been devoted to the study of subjects other than the biological sciences and silvi-

culture. This is clearly illustrated in the following analysis of a standardized curriculum for a 5-year course in forestry, formulated by the Second National Conference on Education in Forestry in New Haven, December 17-18, 1920.*

Standardized Curriculum

5 year course leading to the Master's degree in Forestry.

Subject	*Credit Hours*
General Culture	
English	12
Modern Language	6
History	6
	24
Basic Courses (General)	
Economics	9
Mathematics	10
Physics & Chemistry	15
Meteorology	1
Geology	3
Physiography	3
Elementary Botany	4
Plant Morphology & Anatomy	4
Ecology & Plant Physiology	4
Biology or Zoology	4
	57

*It should not be inferred that this curriculum has been adopted generally by the forest schools. The program of study and emphasis placed upon specific subjects vary considerably in different schools. The curriculum is cited merely as an illustration of the diversified character of the forester's training.

Basic Courses (Specialized)

Business Law	3
Mechanical Drawing	3
Accounting	3
Elementary Mechanics	3
Soils	3
Surveying & Topographic Mapping	12
	27

Technical Forestry Courses

Dendrology	5
Forest Ecology	4
Forest Pathology	3
Forest Entomology	4
Forest Economics	3
Forest Finance	2
Forest Policy	4
History of Forestry	1
Mensuration	7
Forest Engineering	3
Lumber Industry	1
Lumber Business	2
Lumbering	6
Silviculture	7
Seeding & Planting	4
Forest Management	6
Forest Protection	3
Wood Technology	3
Forest Products	4
	72

Although a curriculum covering such a highly diversified list of subjects may be indispensable in training the type of *practitioner* which is most needed in the present state of the development of American forestry, it is not adapted to the training of *investigators* for forest experiment stations. Furthermore, it obviously places a very heavy burden of instruction upon the shoulders of the teaching staff. Thus, when one considers that most of the forest schools have faculties of from 2-4 professors only, and that most of these professors had a similar training, it is not surprising that they should have devoted most of their efforts to teaching and should have given scant attention to research.

A generally awakened interest in research since the War has stimulated many of the forestry schools to initiate programs of investigation and to revise their curricula to permit a wider latitude in election of courses and to afford opportunities for concentration of effort in special fields. Thus, Yale is now placing more and more emphasis upon advanced instruction and research in silviculture, forest pathology, wood technology, lumbering and the economic aspects of forest management. Several schools, *e.g.*, California, Idaho, Montana, are arranging to have each member of their staff devote a portion of the year to purely investigative work. Cornell has appointed research professors in silviculture and in forest soils. Minnesota and Michigan are at present in a transitional phase, but aim to place considerable

emphasis upon research. The N. Y. State College of Forestry at Syracuse, with its huge faculty of thirty professors, has the opportunity of developing investigative work in such varied fields as forest pathology, forest entomology, wood technology, industrial chemistry, silviculture, forest utilization and forest zoology.

That the forestry schools can eventually make important contributions to silvicultural research through the acquisition and management of forests has been demonstrated clearly at Harvard where the university's forest of 2,000 acres has been operated with singular success as a research station and demonstration forest since 1908. The fact that many of the forestry schools have acquired, or are now in the process of acquiring, such tracts of timberland should tend to stimulate the development of much valuable empirical experimental research in forest production.

A considerable portion of those investigations in the descriptive sciences—systematic botany, ecology, morphology, entomology, mycology, etc.—which are significant in forest production has been conducted by institutions which are not directly concerned with forestry. Thus, in the case of systematic botany and ecology, various botanical gardens, arboreta and botanical departments of universities and colleges have rendered invaluable assistance in the reconnaissance of the American forest flora. Similarly much of the work in entomology and phytopathol-

ogy at various educational institutions and agricultural experiment stations has a more or less direct bearing upon forest entomology and forest pathology.

The significance of scientific research for the development of industries no longer needs to be expounded. It has become the policy of a number of industries to support not only investigations which are of immediate help on their own problems but researches of general scientific value as well. Especially has this been the case in physics and chemistry, the results of which most easily and directly find application in the chemical and engineering industries. Certain industries which use forest products have also either contributed to the support of investigations or have themselves conducted such investigations, particularly in connection with processes and products of commercial importance. Thus, the chemical aspects of pulp and paper, naval stores, cellulose lacquers, distillation products, methyl and ethyl alcohol, fiber silks, etc., have been subjected to intensive chemical study. However, the problems of forest production have in general received little attention on the part of industries which are dependent upon a supply of timber. While some of the larger and more progressive concerns have inaugurated programs of forestation and of sustained yield management, as yet comparatively little of this involves comprehensive plans for silvicultural research and experimentation. For some time to come

most of the latter agencies will be concerned primarily with the application of simpler and more rudimentary silvicultural techniques and with such experimentation of a "trial and error" type as is essential for their application.

It is evident that the more intensive lines of descriptive and empirical research in the general field of forest production must be initiated and developed by the Federal Government and by educational institutions. Upon these agencies clearly rests the responsibility of blazing the way for the State forest services, industrial organizations and timberland owners. The task which must be undertaken by the Federal Government and by educational institutions is of very considerable magnitude and is one which is vitally significant in the development and future welfare of forestry in North America. Indeed, the United States with its diversification of species, forest types and environmental conditions has facilities for the gathering and systematic analysis of descriptive and empirical data which are likely to be of the greatest practical and theoretical interest to the entire world.

As has been stated previously, there exist some very fundamental differences between medicine, agriculture and forest utilization on the one hand and forest production on the other in regard to the applications of scientific research. These facts deserve careful consideration. They constitute an important element in the present argument. At the

risk of being redundant, these differences are emphasized again in another way. The present situation in forest production is not entirely dissimilar to that of engineering during the earlier stages of its development. Engineering owes its phenomenal advance to a thorough study of the problems in hand and to the utilization of exact physical and chemical knowledge wherever it may find application. The engineering task has, however, been remarkably simple compared to that of forestry. The problems of engineering, first of all, can be resolved into relatively simple ones and there has been a constantly growing mass of exact physical and chemical data on which to build. The successful application of the methods and concepts of the exact sciences depends to a great extent upon the thorough understanding of the problems in hand and their resolution to the simpler systems which permit of exact treatment.

The problems of forestry have not been thus resolved. Nor are there available the exact data of the basic experimental sciences which may be applied to their solution. Many of the things which the forester expects to get from the basic experimental sciences are not clearly definable and most of them are non-existent. There is a prodigious amount of descriptive and empirical work to be done in forestry before its problems can be resolved and handled profitably by the intensive analytical methods of the exact sciences. In other words, silvi-

culture is still in the pioneer stages of its development and the extensive observational methods of the descriptive sciences, coupled with simple empirical experimentation, afford the most economical and rapid means of establishing such correlations between dominant factors or between groups of phenomena as are of practical significance. Nor should it be inferred that this work, when efficiently done, is of an inferior or less useful nature from the scientific point of view. It hardly needs further emphasis, therefore, that it is in those fields where descriptive and essentially empirical methods of investigation can still yield much valuable information, that there is the most pressing demand for further work in the immediate future. *Forestry cannot now wait for ultimate explanations of the extremely intricate biological phenomena of silviculture which eventually must be supplied through exact and time consuming research in the basic experimental sciences.*

At present, the regional forest experiment stations are seriously handicapped by the difficulty of securing an able and adequately trained personnel of investigators. This is due in part to the fact that the demand for such men is relatively recent, and in part to the fact that the type of work which these men should do, and under existing circumstances can do, has not been defined or visualized with sufficient clarity. Since their inception, the forest schools have been concerned primarily with the training of practitioners, with increasing emphasis upon the indus-

trial and economic aspects of forestry. The faculties of most forest schools have been overburdened with teaching and other responsibilities and have had neither the time for, nor a strong natural urge toward, scientific research. Until comparatively recently, instructors have been chosen without particular reference to their inherent aptitudes and special training as investigators.

The forest schools are now rather abruptly confronted with the problem of developing research projects of their own and of training investigators for the regional forest experiment stations. The task is by no means an easy one, and a number of important factors in the general situation must be visualized accurately if much misguided effort is to be avoided. It must be admitted that, at present, many of the forest schools have neither the resources nor the personnel for suddenly initiating comprehensive programs of research in forest production, such as provide an essential background or environment of research in the efficient training of investigators. Even in the larger institutions real progress is not likely to be attained merely by the expedient of requiring each member of the staff to devote a portion of his time to research activities. The roots of the situation extend far deeper than this. For the training of outstanding investigators of unusually broad vision, such as are required in the pioneer task of developing sound and far reaching programs of research in forest production, the active and sym-

pathetic cooperation of the natural sciences must be enlisted. Herein lie a number of specific difficulties and misconceptions.

It is desirable that the personnel of the regional forest experiment stations be well trained in the natural sciences. But the man who has secured a doctorate in some relatively circumscribed field of science does not, in most cases, thereby fulfill the requirements of the forest experiment stations. This has led, at times, to the dictum that the training in the natural sciences be conducted within the school of forestry. It is, however, clearly fallacious to attempt to train specialists in the descriptive and basic experimental sciences entirely within a school of forestry. This merely substitutes one type of undesirable specialization for another. Advanced training in entomology, phytopathology, genetics, plant physiology, soil science, chemistry, etc., is accomplished best where those sciences are pursued in the broadest and most thorough manner. Even if the sciences are to serve merely as handmaids to forestry, only the most thorough and modern training will suffice, and the stimulus acquired through contact with older and more highly developed researches will mean more than the acquisition of mere facts concerning practical applications in forestry. It is true that the "forestry viewpoint" means much and is a real thing. But, if certain tools and conceptions are to be carried over to forestry, these must be obtained where they are being developed in

the soundest manner. How then may the existing situation be remedied?

The selection and early training of investigators for the general field of forest production should be initiated in institutions which have a school of forestry in conjunction with strong science departments. What is most essential at this early stage of the future investigator's development is a well planned curriculum formulated, in the first place, to enhance his powers of observation, of critically analyzing cumulative circumstantial evidence and of accurately interpreting statistical results, and in the second place to give him a sound, well-rounded training in general science, a broad comprehension of forestry and particularly of the biology of the forest and an adequate reading knowledge of modern languages. Premature specialization, that unfortunate tendency in modern science, should be avoided, concentration in special fields of science or of forest production, *e.g.*, genetics, forest entomology, forest pathology, silviculture, should be deferred to the post-graduate phase and, as previously stated, should be pursued where those subjects are most broadly and thoroughly developed.

Unfortunately there is a lack of real mutual confidence and understanding in many institutions between the forestry and allied science departments which tends to retard, if not actually to inhibit, the development of such curricula. On the one hand, the forester, absorbed as he has been in a complex under-

taking involving many pressing political, economic and commercial factors, commonly has not developed a keen insight into science and the methods of scientific research. He tends to be too exacting and too impatient for quick results in his demands upon the natural sciences, and to over-emphasize the value of a varied program of rather stereotyped, practical forestry courses in the training of investigators. This culminates at times in attempts to give men, trained as practitioners of forestry, a top dressing of graduate instruction in science, which is fully as undesirable as to require a post-graduate, who has concentrated in some special field of science, to take a complete course of practical instruction in forestry. On the other hand, the scientist usually is not fully cognizant of the fact that there are inherent economic and other obstacles to the application of intensive cultural methods in forestry and that the basic experimental sciences have not advanced as yet to a stage where they can contribute effectively in the solution of practical silvicultural problems. He does not visualize accurately the forester's needs and point of view. Not infrequently he is himself a product of premature and excessive specialization and is unwilling or unable to give the broad and generally stimulating type of elementary instruction for which he is officially responsible.

There is at present considerable propaganda for and against specific subjects and methods of inves-

tigating biological phenomena. The forester is unable to judge the real merits of such controversies. The propaganda of the ultra-modern school of so-called fundamental biological research is the more alluring and effective, and the forester, in his ardent desire to enhance the prestige of his profession, is at times in danger of attempting to adopt types of scientific instruction, tools and techniques which are ill adapted to his purposes. Not infrequently it is stated that the work of forest experiment stations should be of a "fundamental" nature, but the connotation of "fundamental" evidently varies and is more or less indefinite. As previously indicated, a number of the descriptive sciences have obvious and important rôles to play in the development of silviculture and their contributions are in one sense fundamental. Although the work in these fields tends to become more and more detailed and intensive as time goes on, the method of attack is essentially empirical. At present, the chief danger lies in attempting to apply sciences which have not developed as yet to the point where they are capable of application, or where the problems have not been visualized sufficiently clearly to make them amenable to truly intensive fundamental investigation. The length of time required, and the difficulties of organization and coordination, in order to develop a thoroughly fundamental approach to the problems of forest production, need to be more generally and clearly recognized by both scientists and foresters.

Different aptitudes, disciplines and psychological outlooks are required in the descriptive, as contrasted with the basic experimental, sciences, and attempts to hybridize the two in a single individual are rarely successful.

It cannot be too strongly emphasized that the future welfare of research in the forest experiment stations is dependent upon the selection and adequate training of an unusually able and outstanding group of investigators. Such leaders are an indispensable element in every pioneer development in research. If such men are to be attracted toward research in the forest field, it is essential, not only that the salary scales and opportunities for advancement be adequate, but that a wholesome and stimulating research environment be developed at the forest experiment stations. If the initiative and activities of the research men are curtailed through excessive centralized direction and supervision, really able investigators cannot be secured or retained permanently.

Considerable time will obviously be required for the rearrangements and changes of points of view which are essential for the selection and training of the right type of men for the regional forest experiment stations. The Federal bureaus have agreed to increase their expenditures gradually rather than to expand suddenly to the maximum limits authorized by the McSweeney-McNary bill. This is a sane and commendable policy.

CAN RESEARCH IN THE BASIC EXPERIMENTAL ASPECTS OF FORESTRY BE DEVELOPED AND HANDLED ADEQUATELY BY EXISTING AGENCIES?

CHAPTER V

Can Research in the Basic Experimental Aspects of Forestry be Developed and Handled Adequately by Existing Agencies?

In the preceding pages the endeavor has been made to outline some of the salient factors which have determined the development of the art of forestry. Many of these considerations are of a general nature and apply to almost the entire world. For reasons already stated, America occupies a unique position in regard to potentialities which may contribute to the solution of universal forestry problems. The situation in America has, therefore, been subjected to special analysis. Herein the chief consideration has been given to the institutions and activities which concern research in various phases of forestry problems, more particularly those affecting, directly or indirectly, forest production. It has seemed important to point out certain fundamental differences between forestry and other fields of endeavor in which research has been applied to extend knowledge. Forestry must be visualized as a huge and intricate structure. For its construction many workers of different types are necessary.

On the one hand, the fact that immediate modes

of procedure are of the greatest urgency and, on the other, that any truly fundamental attack on the problems of forestry entails, first of all, the accumulation of much information of a basic nature involving very extended periods of time, lead to the conclusion that two distinct types of research are essential. First, the securing of more extensive information of a descriptive nature, and the coordination and application thereof through empirical methods, constitutes an immediate necessity which can be met more effectively through existing agencies.

But advancement of forestry through research is faced with a further necessity. In order to discover principles which have a wider and more universal significance, to become familiar with the grounds or the reasons for the phenomena observed, it is essential to analyze more thoroughly and synthesize more securely than is possible by empirical or descriptive methods. Such an undertaking entails the close cooperation of various scientific disciplines and involves the laborious and time-consuming features of exact experimental procedure. Forestry is in a less fortunate position than many arts in that the scientific substratum upon which it must build is for the most part but poorly developed or non-existent. The stones which must be used to construct this foundation are widely scattered and few, and of such poor quality that some cannot be used with safety while others are in such form that they must be hewn and reshaped to meet the needs. These stones cannot be

loosely assembled; they must support each other so that the foundation may be laid deep and secure.

The problem is huge; it has its own characteristics which demand appropriate treatment. The undertaking is in its infancy; it deserves and needs the most modern and effective means conceivable. There are two features of basic forestry research which with others make a special means of attack necessary. These two features are the complexity of the problems and the long time required to attain reliable results from experimental researches. The two are in many respects interrelated. *They are probably more pronounced in forestry research than in any other scientific endeavor yet undertaken.* These features, of themselves, preclude any individualistic or circumscribed approach. Isolated and sporadic efforts, attempts to advance one section of the biological structure without adequate support of the exact sciences, the dissipation of resources and energy in scattered endeavors can produce no advance. On the contrary, with the realization of certain common interests and aims, different disciplines and viewpoints when brought to bear upon the problems can, through mutual support and criticism, clarify these problems and increase the efficacy of each.

In almost every human endeavor, increased complexity has resulted in specialization. But such specialization of itself is of little value. It is only when it is demonstrated that the specialist can make a

better contribution through intensive efforts in a restricted field that specialization becomes justified. Such is undoubtedly the case in the sciences which constitute the foundation of forestry. It needs no further emphasis, however, that no single one of these sciences can grapple successfully with as complex problems as are presented in forestry. No single mind can be in possession of all the facts and concepts of the various special sciences which must be considered in many of the forestry problems. Not only does each generation of scientific workers stand upon the shoulders of the preceding generation, but each specialist gains support and inspiration in his work from other specialists. As a consequence of this situation, the advance in our understanding of forestry problems will be in proportion to the extent to which the various special sciences work together toward a common aim.

The question naturally arises can this type of fundamental research be undertaken and developed effectively by existing agencies? This question brings to consideration first of all the Federal and State forest services. These agencies have for the most part been established for definite and specific purposes. The predominant and pressing demand in these institutions is for practical results and modes of immediate action. As has been repeatedly stated, it is not only essential that this work be done, but there is also a very urgent demand for this work. The dissemination of information gained from ex-

perience and investigation and the guiding of the policy of owners of many types of forest tracts by Federal and State forestry agencies constitutes a public service which can hardly be overestimated. This is, in fact, the direct function and responsibility of these agencies. The broad basis of the Federal Service, the more intimate relations of the State agencies, together with the possible effective co-operative relations of the two, admirably fit these institutions for direct contact with those problems with which the art of forestry can effectually cope in the immediate future. With the growing recognition of the value of the results produced, increased burdens will fall upon the Federal and State agencies. Augmented financial support will inevitably be consumed largely in this manner. Under such circumstances no scientific undertaking, no matter how ideally it has been inaugurated, is proof against pressure exerted by economic and political exigencies. In a democracy this is apparently unavoidable. The incessant urge for applications of scientific research tends to circumscribe its outlook and to prevent the broadest and most fundamental development.

In this connection, there is one aspect of the investigations in the basic and exact sciences as applied to forest production, the significance of which can hardly be over-emphasized. That is that such investigation will of necessity be of the long time type; not only years but decades will be required

before reliable conclusions can in all probability be drawn. A first requisite for such an undertaking is the assurance of a stable and continuing policy. The support for obtaining public funds or facilities for utilizing public institutions is found, on final analysis, to come from the body politic itself. Such support is forthcoming and to a measure assured as long as comprehensible and practical results are visible. At the same time it must be borne in mind that forestry is an eminently practical matter, highly susceptible to economic disturbances. Under these circumstances it is often an impossibility to continue on a course of costly and apparently random and impractical scientific investigations.

Similar considerations apply also to the future research activities of the forest industries. Too close an analogy cannot be drawn between the great manufacturing industries, such as the electrical and telephone industries, and the timber producing industry. The gap between discoveries in the so-called exact sciences and their application in the case of the former industries is much narrower than is the case in forest production. For instance, in the electrical industries, the basic sciences upon which these depend have reached a very much higher stage of development and are relatively much simpler than is the case with forest physiology, soil science, biochemistry and bio-physics. Nor, in all probability, are the forest industries on as sound a financial footing as are many of the electrical industries. Funda-

mental research for the former entails commitment to programs running through decades and generations far beyond the safe prediction for continuance of administrative policy. This is not the case in most of the researches in physics and chemistry undertaken by the electrical industries, in which definite results are attainable much more rapidly. It is, of course, true that placing silviculture upon a thoroughly scientific basis will ultimately remove many of the hazards and uncertainties which now threaten it. However, to accomplish this will require a prodigious amount of work, which considering the uncertain economic aspects of the situation, the forest industries are not likely to feel warranted in undertaking.

The situation in the forestry schools for research in the basic experimental sciences is, in its broadest aspects, not very different from that existing in the Federal and State institutions and in the industries. This is due largely to the fact that the type of training given in the schools has, to a considerable measure, been determined by the latter agencies which are the main employers of forest school graduates. The schools have been concerned primarily with training practitioners and have not the equipment, personnel or point of view to inaugurate sound and effective research in the basic experimental sciences. As has been emphasized in the preceding chapter, the forest schools and the Federal Forest Service are at present confronted with the

difficult task of developing the more intensive lines of descriptive and empirical research in forest production which are essential for the future welfare of the whole forestry movement in North America. The magnitude and complexity of this task is such that it should absorb their combined energies and resources for some time to come. *Furthermore, it is the descriptive sciences and genetics, rather than the basic experimental sciences, which can cooperate most effectively with silviculture in the present stage of its development.*

What has been stated in the preceding paragraphs relative to the adaptability of the Federal and State forest services, industries and forestry schools for research in the basic experimental sciences applies more particularly to the problems of *forest production.* In the field of *forest utilization,* conditions are rather different. Here there are a number of institutions, notably the forest products laboratories and industrial laboratories, which are equipped for intensive experimental researches of different phases of the utilization of forest products, such as pulp and paper, chemical extractives, alcohol, wood preservation, etc. This offers a situation more closely analogous to the engineering industries. For example, basic experimental researches in the chemistry of cellulose, lignin, oleoresins, and other substances may, within a relatively short time, yield results which would profoundly influence many industries which use the substances, or develop en-

tirely new industries. This is, however, due to the fact that those aspects of chemistry that are concerned herein are relatively highly developed, and because in the carrying out of the industrial processes all conditions essential thereto can be controlled. Such intensive basic experimental researches should be encouraged and strongly supported by the existing agencies, not only because they are of value for direct application to the utilization of forest products, but also because they are significant in a better understanding of the physical and chemical properties of forest products and bear indirectly upon many problems of silviculture. Thus, although in the immediate future the work of the regional experiment stations should be primarily of a descriptive and empirical experimental character, the Federal Forest Products Laboratory could well devote an increasing portion of its activities and resources to truly fundamental investigation in the exact sciences. Much of the work of an immediately applicable and practical nature should be performed by the industries themselves, since it is no more than can be expected from the history of other industries that those which derive their profits from forest resources should also support the researches dealing with the practical and immediate aspects of their problems.

While, then, the Federal and State forest services, forest schools and industries do not offer the medium for comprehensive programs of research in those

phases of the basic experimental sciences, upon which the art of forest production must ultimately rest, the question arises whether such programs can be handled adequately by the existing scientific departments of the universities.

As has been indicated in the second chapter of this discussion, the descriptive plant sciences in general, and ecology, plant physiology and soil science in particular, are seriously handicapped at present by the lack of detailed, specific and reliable information concerning the host of interacting physico-chemical reactions in the living plant and in the soil. These phenomena are so complex, so diversified and so extraordinarily variable that in most cases they can be analyzed effectively only through the concatenated and sustained efforts of groups of physical, chemical and biological experts working in close cooperation. The older and relatively stereotyped analytical methods must be refined and perfected, and new techniques developed if real progress is to be made. Science has become dissociated into so many highly technical and specialized sub-divisions that no single investigator can acquire a sound working knowledge of more than a limited portion of the whole field. Attempts upon the part of biologists to master modern chemistry and physics, in addition to one or more of the descriptive sciences, almost inevitably lead to superficiality and tend to encourage a dangerous tinkering with chemical and physical tools and techniques

which are but imperfectly understood. Nor can the biologist solve his problems merely by hiring young chemists or physicists as assistants. The roots of the undertaking must strike deeper than this. The personal interests and convictions of the workers must be enlisted and retained. Can the difficulty be solved through inter-departmental cooperation? Such cooperation cannot be coerced. It must arise through some strong natural stimulus or not at all.

Before attempting to answer this question, it is essential to discuss certain aspects of the present status of science and of scientific research in our universities. The general tendency for science to dissociate into increasingly numerous subdivisions, each with its own particular interests, aims and points of view, has been especially strong in the case of biology. That this tendency has been more pronounced in biology than, for example, in chemistry, is reflected in the organization of numerous biological departments in educational institutions and of the various national scientific societies. Whereas chemistry has succeeded in retaining a considerable degree of cohesion and unity, biology has broken up into a relatively large number of more or less independent units. The problem of stimulating cooperation between individuals in these separate compartments is by no means a simple one, even in the case of those subdivisions of biology which have developed to a stage where problems of mutual concern can be visualized accurately and where

methods and techniques for investigating these problems have been perfected. Thus, although the results which may be attained through cooperative activities between systematic botany, genetics, cytology, pathology, entomology, bacteriology, etc., and between these sciences and agronomy, horticulture and silviculture are fairly obvious, instances of effective inter-departmental cooperation in research, as contrasted with education, are by no means as numerous as might, *a priori,* be expected.

Traditions of an intensely individualistic nature in our universities, as in their European prototypes, have tended to inhibit the development of an atmosphere of mutually beneficial cooperative relations in research. It is not surprising, therefore, that under these self-centering influences and frequent lack of confidence and sympathetic understanding between the theoretical and applied aspects of biology, successive subdivisions, such as bacteriology, plant pathology, economic entomology, genetics, etc., tend to split off from botany and zoology and to become incorporated in separate departments. Although many of the latter units have a common bond of interest in the biological arts, each of them is concerned primarily with its own development. Its energies and resources are absorbed in its own specific and relatively circumscribed activities in education and research. Comparatively little headway has been made as yet in the difficult task of reassembling these dissociated units for concerted attacks upon

those complex biological problems that require concatenated efforts for their solution. Nor is it entirely clear how this may be accomplished most wisely and effectively in existing educational institutions. In the case of the more difficult ecological and physiological aspects of biology, it certainly cannot be accomplished without the active and sympathetic cooperation of physics and chemistry. But at present the gap between physics and chemistry and biology is so wide that it cannot be bridged without some intermediate means of support. On the one hand, the average biologist is unable to resolve his problems into terms that are clearly comprehensible to the chemist or physicist, and, on the other hand, the average chemist or physicist is unable to visualize the numerous variables in biological phenomena. To meet the needs of the biologist, new aspects of physics and chemistry must be developed and refined, and special methods and techniques must be perfected. The existing departments of chemistry and physics have neither the time nor the inclination to assume such burdens. They are absorbed in their own problems and educational activities, and, not infrequently, they systematically discourage their abler students from acquiring an interest in the complexities of biological phenomena.

It has been emphasized repeatedly that the type of research in the basic experimental sciences which is here being advocated as necessary for forestry requires, first of all, a well coordinated group attack

through the concurrent efforts of specialists in various scientific disciplines. In the case of forestry the undertaking must be of a truly basic nature and of wide scope; at least there must be no barrier which may prevent development into fields which at the outset were unforeseen. Such an undertaking cannot recognize artificial divisions of science nor consider academic departments and administrative conveniences which in educational institutions have taken on the aspect of fundamental demarcations. It is of the utmost importance that the interests and growth of a group research project should never become subservient to any other motive but the advancement of the aims for which it was organized. A complex research project, which of necessity must run over many years, if allocated to existing departments will ultimately come into conflict with the traditions and regulations of an educational institution. There will always be differences of opinion within a university regarding its function and a certain competition between the purely pedagogic and research interests. The university has a great variety of duties; aims of university education will always be a subject of dispute; experimentation in university administration is unavoidable.

In other words, the policies of educational institutions are by no means fixed. In State institutions these are subject to political influences from various sources. Such influences may have the most significant consequences. In the privately endowed insti-

tutions, the policies vary radically with changes in the administration. A congenial and earnest research atmosphere with ample support and sympathy for creative work can suddenly change to conditions under which such work is clearly impossible. Such changes may arise from the inevitable shifts in the administrative as well as the faculty personnel; examples are all too numerous in our American universities. A research project intimately connected with the departments of a university must, under such conditions, share the fate of that institution or of some particular department. Nor would it be well for the existing departments of a university to have the course of their free development too strongly influenced by special research projects.

The apportioning of different branches of the basic researches of forestry to scientific departments in *various* universities would have even graver consequences. Not only would the aforementioned administrative problems be multiplied, but the very keystone of the principles of close coordination would be removed. The resulting situation would be quite analogous to the present one. In biology, it is not chiefly more research which is required but sounder research resulting from the direct criticism and assistance which the other sciences, especially the exact sciences, can lend to the methods and conceptions employed in biology.

Somewhat similar considerations to those which have been mentioned in relation to educational insti-

tutions apply to botanical gardens and arboreta. These institutions have been organized for and have had as their chief function the collection, classification and display of plants. Through botanical exploration, gardening and landscape architecture, and exhibition of exotic and cultivated plants, the gardens have rendered a most valuable service to general education, and have fostered an appreciation of the economic and esthetic aspects of plant life. These activities have been of very great value, especially to city dwellers who find herein one of the few remaining means of contact with nature. The more formal and technical activities have centered about systematic botany, and the botanical gardens have thus become also the great depositories for herbaria and collections of fossil plants. These may be of considerable aid in various aspects of forestry, and through cooperation with the scientific staff of experts in different groups of plants much benefit can be derived. Through exploration work, the introduction of exotics, the production and testing of hybrids, and cooperative investigations on the floristic aspects of forest types, the botanical gardens may render valuable assistance in the general field of forestry research.

For investigations in the basic experimental aspects of plant science, botanical gardens and arboreta have not proved to be a medium of permanent value. While this has been due to a variety of causes it is necessary here to discuss only such factors as bear

upon the adaptability of these agencies for researches basic to forestry. A matter of first consideration in this connection is the fact that such researches are predominantly of an experimental nature. For this purpose, a prerequisite of inestimable value is an experimental viewpoint and atmosphere. Without doubt this is a subtle and perhaps even Platonic and transcendental quantity. It is none the less a real element, the *sine qua non* in the development of experimental science. While physics and chemistry have fostered and cherished this element, the plant sciences have not consistently applied it and consequently have not developed the rigorous, exacting and critical attitude that is essential for highly refined and exact experimental work. Moreover, the experimental viewpoint in no small measure conflicts with the traditional activities of botanical gardens and arboreta. Those institutions are already committed to definite tasks and through several hundreds of years have acquired their own precedents and atmosphere. Much of this is unquestionably of great service to mankind, but it is not conducive to the progressive and unhampered development essential to modern experimentation. The botanical gardens and arboreta have already a set pattern into which their activities fit, a scheme of organization and function. There are certain duties which must be discharged; in most cases an elaborate and ever enlarging collection of prepared and living material must be cared for and a constantly growing over-

head provided for this natural growth and the new accessions.

Experimental research cannot remain within fixed boundaries; it should have every degree of freedom. No matter how well defined and specific the original purpose, research in the basic sciences, if it is virile, will grow in directions which are entirely unpredictable. The development of new ideas and of productive workers may lead such research into channels reaching far beyond the original plan. New physical, chemical and biological laboratories and equipment become essential; original lines of endeavor prove fruitless and are abandoned. Flexibility of organization and freedom of development are in the highest degree essential for a rational program of research in the experimental sciences basic to forestry. No greater incumbrance is conceivable than one which would limit this freedom. In some of the older European institutions where the botanical gardens have been intimately affiliated with the laboratories for plant physiology and plant bio-chemistry, the increasing care demanded for the maintenance of botanical collections and displays has greatly hampered the normal development of these sciences on the one hand, and, on the other hand, the emphasis upon experimental work has resulted in the botanical gardens falling into a lamentable condition of neglect.

The value of the ground and of the living material in botanical gardens and arboreta does not permit

the use of these for extensive experimentation. For this purpose there must be available extensive areas which may be put to a variety of uses immaterial of their appearance. Special forest areas in arboreta or affiliated with botanic gardens are of too restricted a nature to permit extensive experimentation of a character required by fundamental forestry research. Such facilities, when required, can undoubtedly be secured advantageously through cooperative arrangements with Federal and State agencies, yielding an extensive range of conditions. Such arrangements would have the added advantage that they would form a means of contact with the workers in the extensive empirical and descriptive investigations pursued by the Federal and State agencies and constitute an avenue through which the two types of investigation could maintain mutually beneficial relations.

It should not be inferred from the preceding discussion that forestry cannot be helped very materially through the allocation of additional funds to specific departments of universities or to botanical gardens and arboreta. As has been stated repeatedly, the descriptive sciences in general and plant pathology, entomology and genetics in particular, have an obvious and important rôle to play in the development of research in forest production. Even the older and essentially descriptive aspects of ecology, physiology, soil science, chemistry and physics may render valuable aid in the investigation of specific practical

problems of silviculture. For such purposes, additional funds are required in the immediate future. However, it is evident that a concatenated and sustained attack upon the more fundamental experimental aspects of forest production cannot be handled adequately by existing scientific departments. For this purpose, new agencies are essential.

NEW AGENCIES REQUIRED FOR RESEARCH, PARTICULARLY IN THE FUNDAMENTAL PHYSIOLOGICAL AND ECOLOGICAL ASPECTS OF FORESTRY.

CHAPTER VI

New Agencies Required for Research, Particularly in the Fundamental Physiological and Ecological Aspects of Forestry.

Many types of agencies have been organized to promote research, discovery and the application of knowledge to human needs. These aims have been realized in universities, special research institutes, museums and botanical gardens, scientific academies, governmental laboratories, industrial organizations and various combinations and modifications of these. Such agencies differ in their adaptation to particular needs and circumstances. Certain undertakings can be carried out more effectively in one type than in another. In fact, one of the most important points throughout this discussion has been that the type of agency and organization should be adapted especially to the nature of the research it is to pursue. This is particularly true where a large and complex group of problems, such as we are here dealing with, is concerned.

It should be recognized that the trend toward the creation of special research units of varying sizes, both within and without educational institutions, is in part an expression of dissatisfaction with the

status, organization and accomplishments of research, and particularly with its subordination to teaching activities and to various administrative expediencies. Many of the older departments in universities have become to no small measure amassers and accumulators of knowledge rather than developers and refiners. The stereotyped outlook of such departments and their absorption in the task of instructing an ever increasing number of undergraduates frequently does not provide a congenial and stimulating environment for research, and hence the urge for the research professorship or the segregation of certain aspects of the field into a new department.

Just as those phases of biology which are especially significant to the biological arts tend to split off from botany and zoology and to become incorporated in separate departments, so the more intensive research activities strive to emancipate themselves from too intimate association with the formalistic and pedagogic interests. There is accordingly a spontaneous urge to incorporate the supposedly more virile and successful investigators in independent or semi-independent compartments of their own. It is, indeed, a natural concomitant of the increasing size and complexity of our educational institutions, of those traditions of an individualistic nature which are so highly cherished and of the general trend of specialization in science.

There are, however, inherent difficulties and dan-

gers in this continued process of differentiation, dissociation and specialization in our universities, and there is obviously a serious question as to how far it may wisely and profitably be allowed to progress. Our universities have distinct educational duties and functions. There is a limit in size and in complexity of organization beyond which the primary aims of an educational institution become obscured in a multiplicity of divers and highly specialized interests, and beyond which productive work becomes constrained by the exigencies of administrative entanglements. A number of our educational institutions are rapidly approaching, if they have not already exceeded, this limit. In any case, they have developed so rapidly and have acquired such extensive resources that attention should now be focused upon the task of refining and of increasing the efficiency of the major projects and lines of endeavor, rather than upon expansion into new fields of activity.

In the general field of forestry, educational institutions, through their forestry schools, have already committed themselves to the task of training practitioners of the art. In addition, they are now faced with the burden of training investigators for the forest experiment stations and of developing research in those special phases of the descriptive sciences which are indispensable concomitants thereof. These tasks have already been alluded to; they are complex and difficult. They involve a large number of pressing problems of vital significance to the future wel-

fare of the whole forestry movement. Intensive and sustained efforts will be required for their solution, since they necessitate fundamental changes in existing points of view, readjustments between individuals and departments, revisions of curricula, etc. Here also the tendency towards specialization seems imminent. Plant pathology, entomology, genetics, etc., are tending to become dissociated from botany and zoology and to affiliate themselves, as separate departments, with agriculture. Should forest pathology, forest entomology, forest genetics, etc., in turn dissociate themselves from the agricultural aspects of these subjects or from botany and zoology, and become incorporated in the forest schools or in separate departments of their own? If so, how may the danger of premature specialization be avoided in the training of investigators? If not, how may effective interdepartmental cooperation be stimulated?

Furthermore, properly trained men are a paramount necessity for complex research undertakings involving the basic experimental aspects of forestry. Sound training in the fundamentals of science must as a rule be obtained at the universities. Therefore, if these complex research projects are to obtain an adequate personnel of investigators, the universities should be so organized as to be able to train these men most effectively.

In view of the complexity and difficulty of such special tasks as these, it would appear to be unwise for the universities to assume in addition the much

more exacting and onerous task of initiating those pioneer researches in the basic experimental aspects of forest production which will require new agencies and a long sustained and well coordinated group attack for their efficient development. To attempt to do so will further complicate a general situation which is already highly involved and will inevitably prove to be a serious distraction in the solution of existing problems and administrative responsibilities.

May not the right type of research institute have a legitimate and essential rôle to play in safeguarding the universities from the danger of over-specialization? May not such an institution function as a valued collaborator rather than as a competitor in the general research field? *The activities of research institutes need not and should not be divorced completely from those of the universities.* In most cases, the research institute should be located in a university environment where stimulating contacts with other scientific workers and possibly with graduate students may be established, and where excessive expansion and needless duplication of effort and equipment may be avoided. At the same time the research institute can be assured of all necessary independence from purely academic and pedagogic control. Under such circumstances, there is no ground for the fear that the universities will lose their best men to the research institutes. The latter should have a distinctly quickening influence on the research activities of the universities, and what these

contribute to the research institutes in men should be repaid by the latter in kind so that ultimately there is an interchange which is beneficial to both.

These statements are made not without the realization that special research organizations have been subjected to much criticism, some of which is thoroughly sincere and deserves careful consideration. It is argued that the creation of special research agencies robs the scientific departments of universities of their ablest investigators, that stimulating contacts with students and with a general university environment are essential for productive theoretical research, that research is a matter for individuals with their coteries of disciples and assistants, that real cooperation between scientific peers is unattainable and merely restricts the freedom and effectiveness of the individual, that independent research organizations inevitably tend to expand and to become increasingly complex and unwieldy and thus to duplicate the activities of universities, that research institutes have not been productive of important original contributions to science in spite of their large resources and elaborate equipment, etc.

In principle, some of these criticisms have already been discussed. However, it must be admitted that serious mistakes have been made in the development of research institutes. In certain cases, there has been an unfortunate tendency to launch them prematurely, without a clear visualization of objectives, on too large a scale, with too circumscribed aims or

without consideration of programs, and *particularly with greatly exaggerated expectations and pronouncements concerning their future contributions.*

To comb the field of science for the most outstanding investigators and to enlist their services through comparatively large salaries, relief from teaching activities and elaborate equipment may have grave consequences. It may not only tend to arouse misconceptions and even hostility among scientific colleagues, but to create a staff whose remaining period of productive research is relatively brief and *especially to produce an unwholesome urge for quick and spectacular results.* If the staff consists of permanent appointees without provision for a considerable inflow and outgo of younger investigators the activities of the institute sooner or later become unduly rigid and stereotyped. Under such conditions the broader educational aspects, which every research institution should foster, are lost and thus also one of its greatest means of influence. Nor may effective cooperation be expected from the association of specialists who are selected without regard to their personal points of view, eccentricities and prejudices.

It should be emphasized in this connection, however, that there are many types of research institutes which vary greatly in size and complexity, in organization, in the specific aims for which they are created and in their degree of isolation from or affiliation with universities. To single out a particu-

lar type of organization as the basis for generalized criticisms of the whole institute idea is obviously unfair.

In many respects the two agencies for scientific research, the university and the research institute, overlap. They should, in fact, be side by side, not as competitors, but as close cooperators. The research institute in no sense relieves the university of the responsibility for research activity. Certainly the training of young people in the advanced aspects of science can be most effectively carried out in an atmosphere of scientific inquiry and by men familiar at first hand with the development of science. Consequently the research institute does not change this aspect of the university's function, if anything the research institute should make its own contribution to the educational work.

Research institutes, to be effective, should not remain stereotyped. They must have many degrees of freedom and a flexible organization; funds must be mobile and not completely petrified in buildings and budgets. New discoveries necessitate ready adjustment in different lines of activity. Therefore, original lines of attack must be abandoned and new ones inaugurated. It is difficult for universities to follow such a policy of freedom. They must always meet their responsibility of educating and training the oncoming generation in the fundamental subjects. Of necessity, they must have greater stability and be encumbered by larger equipment. These are the fea-

tures that differentiate the two agencies. Certain fields of investigation can be developed most effectively in universities. Others of a more complex nature, demanding a concatenated attack of long duration and flexible organization are best pursued in a research institute.

What, then, are some of the means of approach to the development of forest production through research in the more fundamental aspects of the underlying sciences?

It should be emphasized again in this connection that, whereas many of the more descriptive aspects of the natural sciences have progressed to a stage where cooperation with silviculture is both possible and desirable, *i.e.,* where problems of mutual interest are clearly definable and where the necessary tools and techniques for their solution are readily available, the basic experimental aspects of plant science occupy at present an entirely different position. It is a striking fact, observed by many European and American foresters, that silviculture, which deals primarily with living trees, has available comparatively little in the form of exact information concerning the normal functioning of arborescent plants. The tree as a subject for intensive physiological study has been neglected. Thus, a knowledge of the normal physiology of trees and of the forest remains one of the great *desiderata* of silviculture. It clearly falls into the general domain of plant physiology and of ecology, but the latter subdivisions of science

are poorly developed from the basic experimental point of view. Without the support of sound physics and chemistry, they are relatively ineffective weapons of attack. Thus far, plant physiology has dealt primarily with the smaller plants and with lower organisms. While this has been of some service to agriculture, the problems of silviculture require a different mode of attack, not only for the individual arborescent species, but for the whole forest complex. *A new science of forest physiology, involving both physiology of the tree and of the forest, must be developed.*

The study of the tree as a physical system and the determination of the substances thereof and of the chemical reactions which take place within the tree are some of the primary prerequisites for a physiological treatment of its functioning. To obtain special physical and chemical information of this nature requires serious and long continued study. New tools and techniques must be developed and refined. Such tasks, first of all, demand well-trained physicists and chemists, not merely temporary assistants who supplement the efforts of the plant physiologist. But that is not all. The tree is a complex system. The functioning of the tree can not be studied intelligently without consideration of its structure. The latter itself constitutes a difficult and intricate study. Consequently the anatomist and cytologist must join forces with the physicist, chemist and physiologist in the whole attack. The normal physi-

ology of the tree involves not only a consideration of its structure, composition and functioning but of the influence of external factors as well. The effect of air-temperature, light, humidity, etc., must all be analyzed, the whole complex of environmental factors subjected to the same basic treatment. Here again physics plays a dominant rôle. Moreover the all-important and hidden portions of the tree, the root systems, have their own environment, the soil. The latter presents a whole group of problems which have their purely physical, chemical and biological aspects. None of these can be entirely segregated, they are all interrelated. The intricate relations of the microorganisms within the soil, with the accompanying physical and chemical changes, constitute an environmental factor of foremost significance in a consideration of the normal physiology.

The physiological approach, moreover, offers a rational means of advance to other basic aspects of silvicultural problems. Many phases of forest pathology and forest entomology must await a clearer understanding of the normal functioning of trees. A thorough knowledge of the physiology of the host is indispensable to a rational treatment of parisitological problems. Not only would forest pathology and forest entomology make use of knowledge of the internal physiology of trees, but the research activities on the influence of external factors and of those in forest soils could contribute materially to the solution of the more complex problems of forest

production. Furthermore, an intensive study of the abnormal functioning of trees will in many cases throw much light upon their normal physiological activities. Similarly, opportunities exist for the development of essential cooperative relations between genetics, physiology and pathology.

If we are to construct a picture of the normal and abnormal functioning of trees, it must necessarily be made up of many parts. Impressionistic rendering of some of these is hardly in keeping with the scientific accuracy of the rest. On the exact rendering and on its congruity depends the value of the picture to foresters and to others. The greatest advantage lies in bringing together groups with different viewpoints, enabling each to discuss freely and informally his own aspect and to construct thus a truer picture of the whole phenomenon than is possible when this is viewed from one restricted field. The difficulties of realizing such an idea are, however, by no means few. It cannot be accomplished in an atmosphere where traditions are of individualistic nature and consequently antagonistic to such an undertaking. Much depends upon the leadership of the various groups as well as on their personnel. Moreover, simply placing men together does not create cooperation. The personal interests and convictions of the workers must be enlisted. There are a host of purely physical and chemical problems which can engage the attention of the best talent, whose understanding of the

general aims must be enlisted in order to be of service to the other sciences. Such cooperation need in no wise hamper individual initiative and personal effort, nor stifle original ideas. It should, on the contrary, give greater opportunity for both the development and expression of ideas by individual workers.

It is evident that a special undertaking of this character should not be farmed out in disjointed fragments to the existing departments of one or more universities. Nor would it be wise for a single university to have the course of its free development too strongly influenced by assuming the entire responsibility for a specific project of this magnitude and complexity. Furthermore, as shown in the preceding chapter, it is of utmost importance that the interests and growth of this group research project should never become subservient to any other motive but the advancement of the aims for which it was organized. A matter of paramount importance is a clearly visualized and assured policy continuing over a long period of years. It is difficult to safeguard the maintenance of such a project in universities, since the interests, objectives and policies of our educational institutions are subject to sudden and more or less profound fluctuations with changes of administration and of other factors.

The writers have, therefore, been forced to the conclusion that in the long run the interests both of forestry and of educational institutions can be served

best if the task of initiating, developing and guiding researches in the more basic experimental aspects of forest production is assumed by some special administrative agency. The Kaiser Wilhelm Gesellschaft may serve as an example of such an institution. It should be free to accept funds from various sources for consistent and carefully planned projects.

This institution should function not only as a central administration for funds contributed for the special purpose of furthering researches in the basic experimental aspects of forestry, but as an indispensable correlating and coordinating agent in the disbursement of such resources. One of its first and most important tasks should be a careful study of the status of different basic sciences in their relation to forestry problems. Especially in view of the long time feature of such researches, the most careful consideration must be given to the problems to be studied and to the most advisable means of approach. This cannot be done from a single viewpoint, but the problems must be considered from the viewpoints of the various sciences which may be called upon to assist in the attack. This must be the first step in a cooperative effort and should result in clarifying the picture of the problems. Only through the subsequent intensive cooperative researches can the feasibility of the plan of attack be discovered. In sciences as young and undeveloped as those here considered, such changes are unavoidable. This emphasizes the

necessity for freedom of development in any direction, and of cautious and centralized cooperative planning or modes of attack.

Correlations must also be established ultimately with the descriptive and empirical investigations in forestry conducted by Federal, educational and other agencies. New methods and techniques can be devised and old ones tested in order to determine the scientific reliability and degree of usefulness of these methods, which can then be put into the hands of the empirical workers. Reliable instrumentation depends upon sound physical research, and the significance of a vast amount of ecological and other observational investigation is vitiated by faulty instrumentation and a disregard of the physical principles upon which the instruments used depend. The institution must stand for the most thorough and basic development of all the subjects for which it assumes the responsibility. It should be equipped to serve in the capacity of counselling and assisting in matters pertaining to the applicability of methods and concepts of the basic experimental sciences to the descriptive and empirical investigations of forestry. This, of course, in no sense implies the supervision of the latter investigations. Nor is the idea to exercise any coercion on the part of the institution to inaugurate a universal plan of investigation to be followed by other forestry agencies. On the contrary, it should be the function of this agency rather to carry out those activities which existing agencies are ob-

viously incapable of performing, but for which there is a fundamental need.

With the aims and viewpoints established and major projects mapped out, the drawing of specialists from educational and other institutions into such an undertaking through cooperative arrangements would be mutually helpful. Highly specialized researches would thus be strengthened, while the desultory tendency of such researches in biology would be stabilized through the major activities of the institution.

These activities should not involve the creation of a single, large, isolated research institute, but rather the development ultimately of several smaller research units which should be located in university centers and affiliated more or less informally with existing scientific departments. Research thrives best and is most productive in compact semi-independent units of moderate size where the investigators are closely and informally associated, but where they are able to maintain contacts with general scientific and intellectual interests.

The objectives of a special research organization must extend beyond the securing of knowledge regarding fundamental problems. The influence and value of such an institution are largely determined by the service which it renders. It is with this in mind that the creation of the type of research institutes mentioned is being urged. In order to justify themselves, these research units must not only ad-

vance knowledge in certain fields, they must also serve a special educational function. However, owing to the necessarily highly specialized nature of their work, neither direct means of education nor attempts at practical applications of the results of researches can be undertaken without great sacrifices. Their educational function lies in another and more neglected field. The research units should become centers of investigation for various branches of basic experimental science applicable to forestry. There are at present very few men in America or abroad who through training and experience are suited for this work. Younger men must be selected and trained. The nucleus of the research institutes must of necessity be small and carefully chosen. As research developments in the forest experiment stations, forestry schools and other institutions warrant, an exchange of young men should evolve, by means of which the work and experience of the research institutes can be carried to these institutions. Such training cannot be obtained in a few years; it is not a matter of courses, of lectures nor of stereotyped education, but rather of a highly specialized type, obtainable only through years of intimate contact with these disciplines and with the men who are developing them.

Such research institutes should, moreover, offer facilities for workers from other forestry institutions to spend some time in obtaining intensive training and in pursuing researches in the basic experimental

sciences on special aspects of forestry problems. Such an interchange of mature men should result ultimately in a general stimulation and quickening of forestry research the world over.

It is impossible to forecast the directions in which thorough research undertakings in the basic experimental sciences will develop. Nor does it seem wise to outline specifically the work which should be begun. This depends upon a number of factors involving the selection and training of an adequate personnel, etc. It is, therefore, of the greatest importance that the research institutes be developed with extreme caution, that they start on a small scale and that they be allowed to grow as the needs present themselves and especially as the proper personnel becomes available. Such beginnings, however, should carry the positive assurance that adequate means for growth are available as the researches demonstrate the need and justification for expansion. This should include not only developments within the research institutes themselves but it should also offer facilities for the training of younger workers, and particularly for conducting cooperative researches with agencies for descriptive and empirical investigations on the one hand, and with special researches in educational institutions on the other.

From the forests, man has drawn much of his power and inspiration. That it is essential to perpetuate these natural resources needs no special

pleading. The object of this discussion has been to indicate the most effective means of meeting the needs of forestry through the application of scientific investigation. These needs are varied, complex and exacting—probably far more so than any which science has yet attempted to supply. Other endeavors in applying the scientific method to human needs, as in industry, medicine and even agriculture, which on first thought might be considered as yielding valuable analogies, on careful examination disclose many fundamental differences.

An attempt has been made to indicate in what manner the more immediate needs of silviculture may be met. A more thorough understanding of the exceedingly complex and intricate biological interrelations of the forest requires the combined efforts of various scientific disciplines. This is inevitably a long and arduous task, for new viewpoints and conceptions must be brought to light, new methods devised. In short, the science of trees and of forests must be developed in its most basic aspects.

It is a challenge to America. Here, if anywhere, are both the will and the financial means for accomplishing it. Beyond that, America has an even more precious heritage. Nature's own husbandry, as found in the remaining primeval forests, will ever be man's best teacher.

* * * * * * *

APPENDIX

LIST OF INSTITUTIONS VISITED.

APPENDIX.

As basic for the preparation of the preceding discussion, it was essential to make a critical analysis of the aims, methods and organization of representative institutions devoted to the study of forestry problems, to learn at first hand the work which is being done in the sciences fundamental to forestry and to discuss the problems intimately with leading authorities in these fields. This involved considerable travel in Europe and North America which was facilitated through the generosity of the General Education Board. Principally those institutions and lines of research were studied with which the writers were not already familiar. Cordial assistance was rendered by many, in America and Europe, and it is a pleasure to express our sincere appreciation of this generous cooperation.

The following is a list of the institutions visited.

ENGLAND.

London:

The Imperial College of Science and Technology.

Laboratories for Botany.

Laboratories for Plant Physiology.

Laboratories for Biochemistry.

Laboratories for Bacteriology.

University College.
Laboratories for Botany.
Laboratories for Plant Chemistry.
Laboratories for Biochemistry.
Laboratories for Physiology.
Forestry Commission.
Department of Scientific and Industrial Research.
Royal Botanic Gardens, Kew.
Chelsea Physic Garden.

Harpenden, Herts:
Rothamstead Experiment Station.
Institute of Plant Nutrition and Soil Problems.
Institute of Plant Pathology.

Reading:
The University of Reading.
Laboratories for Botany.
Laboratories for Agricultural Botany.

Leeds:
The University of Leeds.
Laboratories for Botany.

Liverpool:
The University of Liverpool.
Department of Botany.
Department of Chemistry.

Cambridge:
The University.
Laboratories for Botany.
Laboratories for Plant Physiology.
Laboratories for Biochemistry.
Forestry School.
Low Temperature Research Laboratories of the Board of Scientific and Industrial Research.

Oxford:
The University.
Forestry School, Experimental Forest and Nursery.
The Imperial Forestry Institute.

Brockenhurst:
New Forest. Plantations.

South Farnborough:
Forest Products Research Laboratories.

DENMARK.

Copenhagen:
Kobenhavns Universitet.
Laboratories for Botany and Botanical Garden.
Laboratories for Plant Physiology.
Laboratories for Chemistry.
Landbohöjskole.
Laboratories for Botany.
Laboratories for Plant Physiology.
Laboratories for Chemistry.
Department of Forestry.

Klampenborg:
Skoven Forest.

NORWAY.

Oslo:
Kongelige Frederiks Universitet.
Department of Chemistry.

Aas:
Norges Landbrukshöiskole.
Department of Forestry.
Department of Soil Science.
Department of Botany.
Department of Chemistry.
Norwegian Forestry Service.

Bergen:

Bergens Museum.
Biological Station.
Norwegian Forestry Service.

SWEDEN.

Stockholm:

Stockholms Högskola.
Laboratories for Botany.
Laboratories for Biochemistry.
Nobel Institute, Experimentalfältet.
Centralanstalten för Försöksväsendet på Jordbruksområdet, Experimentalfältet.
Laboratories for Chemistry.
Laboratories for Soil Science.
Laboratories for Botany.
Statens Skogsförsösanstalt, Experimentalfältet.

Simlondalen:

Forestry Experiment Station.

Svalöf:

Sveriges Utsadesforening.

Hallands Väderö:

Ekologiska Stationen.

Landskrona:

Dr. Nils Herbert-Nilsson, Weibullsholm.

Lund:

Kungl. Karolinska Universitetet.
Laboratories for Physiology.
Laboratories for Biochemistry.

FINLAND.

Helsinki:

Helsingin Yliopisto.

Laboratories for Botany and Botanical Garden.

Laboratories for Plant Physiology.

Forestry School.

Forstvetenskapliga Försokanstalten (Forest Research Institute of Finland).

Board of Forestry.

Foresters School, Ekenäs.

Forest Institute, Evo.

Pekola, Hattula:

Estate of Senator A. Osw. Kairamo, Foreign Species of Culture Experiments.

Åbo:

Åbo Akademi.

Wood-Chemical Department.

GERMANY.

Berlin:

Friedrich-Wilhelms-Universität.

Institute for Plant Physiology, Berlin-Dahlem.

Institute for Botany, Berlin-Dahlem.

First Chemical Institute.

Kaiser Wilhelm-Institut für Biologie, Berlin-Dahlem.

Kaiser Wilhelm-Institut für Biochemie, Berlin-Dahlem.

Biologische Reichsanstalt, Berlin-Dahlem.

Chemische Reichsanstalt.

Eberswalde:

Preussische Forstakademie.

Preussische Forstliche Versuchsanstalt.

Forstliche Samenprufünganstalt.

Leipzig:

Universität.

Botanical Institute and Botanical Garden.

Chemical Institute.

Agricultural Institute.

Tharandt:

Sächsische Forstliche Hochschule.

Sächsische Forstliche Versuchsanstalt.

Stuttgart:

Technische Hochschule.

Botanical Institute.

Chemical Institute.

Württembergische Forstliche Versuchsanstalt.

Hohenheim:

Landwirtschaftliche Hochschule.

Botanical Institute.

Freiburg im Breisgau:

Albert-Ludwigs-Universität.

Forestry School.

Forestry Experiment Station.

Soil Institute.

München:

Ludwig-Maximilians-Universität.

Botanical Institute and Garden, Nymphenburg.

Chemical Institute.

Forestry Experiment Station.

Heidelberg:

Ruprecht-Karls-Universität.

Botanical Institute.

AUSTRIA.

Wien:
- Universität.
  - Institute for Plant Physiology.
  - Institute for Botany.
- Hochschule für Bodenkunde.

Mariabrunn:
- Deutsch-Österreichische Forstliche.
- Bundesversuchsanstalt.
- Forstlicher Versuchs-und Demonstrationsgarten.

SWITZERLAND.

Zürich:
- Universität.
  - Institute for Botany.
  - Institute for Chemistry.
- Eidgenössische Technische Hochschule.
  - Institute for Plant Physiology.
  - Forestry School.
  - Forestry Experiment Station.
  - Institute for Chemistry.

Basel:
- Universität.
  - Institute for Botany and Botanical Garden.

CZECHOSLOVAKIA.

Prag:
- Karlova Universita. (Czech)
  - Institute for Botany.
- Universität. (German)
  - Institute for Botany.
- Vysoká Škola Zemědélského a Lesniho Inženýrstvi.
  - Agricultural School and Experiment Station, Uhriněvěs.

Brno:

Masarykova Universita.

Institute for Botany.

Institute for Plant Physiology.

Institute for Physiology.

Institute for Physical Chemistry.

Institute for Organic Chemistry.

Vysoká Škola Zěmědělská. (High school for Agriculture and Forestry.)

Laboratories for Biochemistry.

Laboratories for Agricultural Chemistry.

Laboratories for Soil Science.

Laboratories for Botany.

Laboratories for Zoology.

Forestry School.

Forestry School and Experimental Forest, Adamov.

Deutsche Technische Hochschule.

Laboratories for Plant Physiology.

NETHERLANDS.

Wageningen:

Landbouwhoogeschool.

Institute for Plant Physiology.

Institute for Microbiology.

The Forestry School and Arboretum.

Utrecht:

Rijks Universiteit.

Laboratories for Plant Physiology and Botany.

Amsterdam:

Universiteit van Amsterdam.

Laboratories for Plant Physiology and Botany.

Botanical Garden.

Groningen:
Rijks Universiteit.
Laboratories for Plant Physiology and Botany.
Botanical Garden.

FRANCE.

Paris:
Collége de France.
Laboratories for Plant Physiology.
La Sorbonne.
Laboratories for Plant Physiology.
Laboratories for Cytology.
Laboratories for Agricultural Biology.
Institut des Recherches Agronomiques.
Laboratories for Plant Pathology.
Laboratories for Entomology.
Jardin des Plants.
Musée National d'Histoire Naturelle.
Laboratoire Colonial.

Nancy:
École Nationale des Eaux et Forêts.

CANADA.

Ottawa, Ont.:
Forestry Branch.
Entomological Branch.

Toronto, Ont.:
The University of Toronto.
Department of Botany.
Department of Forestry.

Montreal, Que.:
McGill University.
Department of Botany.
Canadian Forest Products Laboratory.

Fredericton, N. B.:
Dominion Forest Entomological Laboratory.

UNITED STATES.

New Haven, Conn.:
Yale University.
Forestry School.
Botanical Department.
Connecticut Agricultural Experiment Station.

Yonkers, N. Y.:
Boyce Thompson Institute.

New York City:
N. Y. Botanical Garden.
Columbia University.
Botanical Department.

Ithaca, N. Y.:
Cornell University.
Botanical Department.
Forestry Department.

Syracuse, N. Y.:
N. Y. State College of Forestry.

Washington, D. C.:
U. S. Department of Agriculture.
Forest Service.
Bureau of Entomology.
Bureau of Plant Pathology.

Ann Arbor, Mich.:
University of Michigan.
Botanical Department.
School of Forestry.

Chicago, Ill.:
University of Chicago.
Botanical Department.
Chemistry Department.

Madison, Wis.:
U. S. Forest Products Laboratories.
University of Wisconsin.
Botanical Department.
Department of Plant Pathology.
Department of Genetics.
Department of Soils.
Burgess Laboratories.

St. Paul, Minn.:
Lake States Forest Experiment Station.
University of Minnesota.
Botanical Department.
Forestry Department.
Department of Genetics.
Department of Plant Pathology.
Department of Biochemistry.

Cloquet, Minn.:
Forest Experiment Station.

Missoula, Mont.:
Northern Rocky Mountain Forest Experiment Station.
University of Montana.
Department of Botany.
School of Forestry.

Seattle, Wash.:
University of Washington.
Department of Botany.
College of Forestry.

Portland, Ore.:
Pacific Northwest Forest Experiment Station.
Office of Plant Pathology.

San Francisco, Calif.:
District Headquarters, Forest Service.
Office of Plant Pathology.

Berkeley, Calif.:
California Forest Experiment Station.
University of California.
Department of Botany.
Department of Forestry.
Department of Plant Nutrition.
Department of Genetics.
Department of Pomology.
Department of Subtropical Horticulture.

Palo Alto, Calif.:
Stanford University.
Department of Botany.
Department of Economic Biology.

Los Angeles, Calif.:
University of California, Southern Branch.
Botanical Department.

Riverside, Calif.:
Citrus Experiment Station.

Flagstaff, Ariz.:
Southwestern Forest Experiment Station.

Albuquerque, N. M.:
District Headquarters, Forest Service.
Office of Plant Pathology.

Colorado Springs, Colo.:
Rocky Mountain Forest Experiment Station.
University of Colorado.
School of Forestry.

Bailey
The rôle of research in the development of forestry in North America.